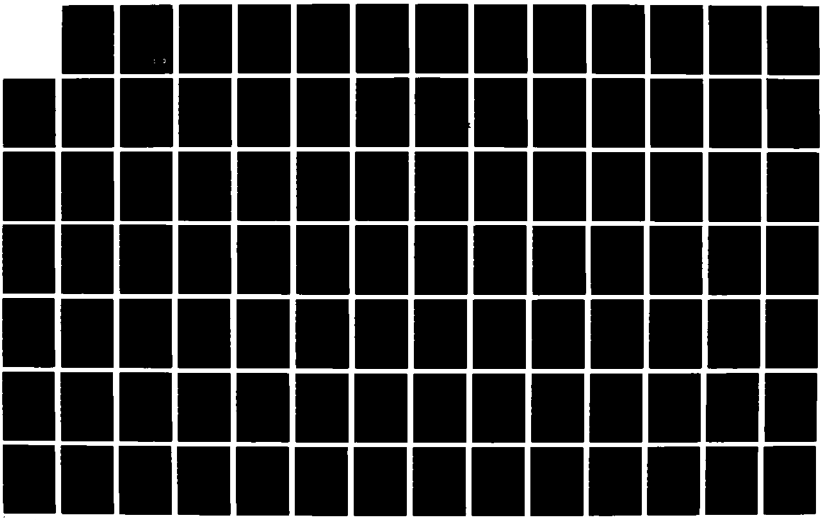
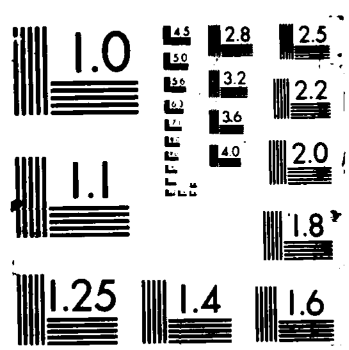
AD-A186 153 THE APPLICATION OF MATHEMATICAL PROGRAMMING TO THE PRODUCTIVITY INVESTMEN..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH D S CHRISTENSEN 1987 1/3

UNCLASSIFIED AFIT/CI/NR-87-133D F/G 12/4 NL




1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

DTIC FILE COPY

AD-A186 153

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AFIT/CI/NR 87-133D
2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): The Application of Mathematical Programming To The Productivity Investment Fund Program: A Capital Rationing Problem
5. TYPE OF REPORT & PERIOD COVERED: ~~THESIS~~/DISSERTATION
6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): David Scott Christensen
8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: AFIT STUDENT AT: University of Nebraska
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: AFIT/NR WPAFB OH 45433-6583
12. REPORT DATE: 1987
13. NUMBER OF PAGES: 192
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
15. SECURITY CLASS. (of this report): UNCLASSIFIED
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report): APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)
18. SUPPLEMENTARY NOTES: APPROVED FOR PUBLIC RELEASE: IAW AFR 190-1

Lynn Wolaver 16 Oct 87
LYNN E. WOLAVER
Dean for Research and Professional Development
AFIT/NR

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
20. ABSTRACT (Continue on reverse side if necessary and identify by block number): ATTACHED

DTIC ELECTE NOV 24 1987 S D H

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

THE APPLICATION OF MATHEMATICAL PROGRAMMING TO
THE PRODUCTIVITY INVESTMENT FUND PROGRAM:
A CAPITAL RATIONING PROBLEM

David Scott Christensen, Ph.D.

University of Nebraska, 1987

Advisor: James F. Brown, Jr.

This study explores the potential application of mathematical programming (MP) to a capital rationing problem of the Department of Defense ~~(DoD)~~. It demonstrates that the current method of selecting projects for funding results in a suboptimal economic mix of capital investment projects. Based on data from the Fiscal Year 1985 ~~(FY85)~~ Productivity Investment Fund (PIF) program, substantial dollar savings are likely if PIF projects are selected using MP instead of ranking.

Using a single-criterion MP model, the opportunity cost of ranking (defined as the difference between the net present value (NPV) the mix found by MP and the NPV of the mix actually funded by the DoD) was $205.6 million. The economic superiority of the MP-selected mix was demonstrated over broad ranges of budget ceilings and discount rates. The average opportunity cost of ranking ranged from $23 million to $242 million, depending on the ranking criterion or method used.

Two multiple-criteria MP models were also developed and tested using the FY85 PIF data. The mixes found by these models were economically superior to those found by ranking, when pre-specified objectives (involving minimum levels of return on investment and labor savings) were set for the solution mix.

SELECTED BIBLIOGRAPHY

Primary Sources

Bernhard, R. "Mathematical Programming Models for Capital Budgeting--A Survey, Generalization, and Critique." Journal of Financial and Quantitative Analysis 4 (June 1969), pp. 111-158.

Carleton, W. "Linear Programming and Capital Budgeting Models: A New Interpretation." Journal of Finance 24 (December 1969), pp. 825-833.

Elton, E. "Capital Rationing and External Discount Rates." Journal of Finance 25 (June 1970), pp. 573-584.

General Management Systems. Qualification of Productivity Enhancing Investment Potential. Falls Church, Virginia: Defense Productivity Office, 1986.

IBM Mathematical Programming System Extended/370 Program Reference Manual, 4th ed. IBM Corporation, 1979a. Form number SH19-1095.

Schrage, L. Linear, Integer, and Quadratic Programming With LINDO. Palo Alto: The Scientific Press, 1984.

Weingartner, H. Mathematical Programming and the Analysis of Capital Budgeting Problems. Englewood Cliffs, New Jersey: Prentice Hall, 1963; reprint ed., Chicago: Markham Publishing Company, 1967.

Secondary Sources

Finn, F. "Integer Programming, Linear Programming and Capital Budgeting." ABACUS (December 1973), pp. 180-192.

Folger, H. "Ranking Techniques and Capital Budgeting" The Accounting Review 47 (1972), pp. 134-143.

Geoffrion, A. and R. Nauss. "Parametric and Postoptimality Analysis in Integer Programming."Management Science 23 (January 1977), pp. 453-466.

Ignizio, J. Goal Programming and Extensions. Lexington, Mass.: Lexington Books, 1976a.

Keen, P. "The Evolving Concept of Optimality." In Multi-Criteria Decision Making, pp. 31-57. Edited by M. Starr and M. Zeleny. New York: North Holland Publishing Co., 1977.

Lee, S. and A. Lerro. "Capital Budgeting for Multiple Objectives." Financial Management 3 (Spring 1974), pp. 58-66.

Lenio, E. "The Introduction of Uncertainty Techniques to the Productivity Investment Fund." Thesis, Naval Post Graduate School, Monterey, California, 1984.

Lorie, J. and L. Savage. "Three Problems in Capital Rationing." The Journal of Business 28 (October 1955), pp. 229-239.

Masud, A. and C. Hwang. "Interactive Sequential GP." Journal of Operational Research Society 32 (1981), pp. 391-400.

Pinches, G. "Myopia, Capital Budgeting and Decision Making." Financial Management (Autumn 1982), pp. 6-19.

Spronk, J. Interactive Multiple Goal Programming, Applications to Financial Planning. Boston: Martinus Nijhoff Publishing Company, 1981.

Stockfisch, J. Testimony before the Subcommittee on Economy in Government, Joint Economic Committee. The Planning, Programming, Budgeting System: Progress and Potentials. 90th Congress, 1st sess. (20 September 1967), pp. 133-143.

Weingartner, H. "The Excess Present Value Index--A Theoretical Basis and Critique." Journal of Accounting Research 1 (Autumn 1963), pp. 213-224.

________. "Some New Views on the Payback and Capital Budgeting Decision." Management Science 15, (August 1969), pp. B594-B607.

________. "Capital Rationing: n Authors in Search of a Plot." The Journal of Finance 32 (December 1977), pp. 1403-1431.

THE APPLICATION OF MATHEMATICAL PROGRAMMING TO THE PRODUCTIVITY INVESTMENT FUND PROGRAM: A CAPITAL RATIONING PROBLEM

by

David S. Christensen

A DISSERTATION

Presented to the Faculty of

The Graduate College in the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Doctor of Philosophy

Major: Interdepartmental Area of Business (Accounting)

Under the Supervision of Professor James F. Brown, Jr.

Lincoln, Nebraska

August, 1987

TABLE OF CONTENTS

	Page
ABSTRACT	ii
LIST OF TABLES	vi
LIST OF FIGURES	viii
ACKNOWLEDGEMENTS	ix
Chapter	
1. INTRODUCTION	1
Background	1
Statement of Problem	3
Objectives	4
Contributions	4
Potential Limitations	7
Organization	8
2. THE PRODUCTIVITY INVESTMENT FUND (PIF) PROGRAM AND THE LIMITATIONS OF RANKING	10
The PIF Program	10
Limitations of Ranking	21
Conclusion	25
3. THE MATHEMATICAL PROGRAMMING APPROACH AND ITS LIMITATIONS	27
The Mathematical Programming Approach	27
Exhaustive Enumeration	28
Early MP Algorithms	29
Weingartner's Formulation	30
The Limitations of MP	32
The Discount Rate Limitation	32
Hard Rationing	32
Soft Rationing	36
The Social Cost of Capital	37
Sensitivity Analysis	44
The Multiple Objective Limitation	46
The Uncertainty Limitation	51
The Computational Efficiency Limitation	54
Conclusion	55

4. METHODOLOGY 58

Research Design 59
Procedures for Dealing with MP Limitations in the Context of the PIF Program 68
The Discount Rate Limitation in Context . 68
The Multiple-criteria Limitation in Context 71
The Uncertainty Limitation in Context . . 72
The Computational Efficiency Limitation in Context 73
Specific Procedures and Methodological Details 74
Hypothesis Testing 74
The Multiple-criteria Demonstration . . 76
The ROI Model 76
The Sequential GP Model 77
Sensitivity Analysis 79
Range Analysis 80
Cross-over Analysis 80
Supplemental Analysis 83
The PIF Database 84
Tools Used in the Study 87
Summary 87

5. RESULTS 90

Results of the Single-criterion Model . . . 91
Conflicting Rankings Confirmed 92
Hypothesis Confirmed 97
Sensitivity Analysis 97
Range Analysis 97
Cross-over Analysis 104
Additional Analysis 107
The LP Solution Mix 107
The Relative Effectiveness of Ranking Criteria 109
Multiple-criteria Demonstrations 110
Results of the ROI Model 111
Results of the Sequential GP Model 115
Conclusion 118

6. SUMMARY, CONCLUSION, AND SUGGESTIONS FOR FUTURE RESEARCH 121

Summary 121
Conclusion 125
Suggestions for Future Research 126

APPENDIX 129

SELECTED BIBLIOGRAPHY 179

LIST OF TABLES

Table		Page
1.	The Productivity Enhancing Capital Investment Program	12
2.	PIF Projects Submitted by DoD Components	15
3.	PIF Projects Approved by OSD	15
4.	The Appropriate Discount Rate	33
5.	Estimates of the Social Discount Rate	42
6.	Summary of MP Limitations in Capital Rationing	57
7.	Summary of the Sequential Goal Programming Model	79
8.	Summary Statistics on FY85 PIF Project Data	85
9.	Summary of the Three MP Models	89
10.	IP Solution Mix Compared to Mixes Determined by Ranking (Budget Ceiling = $73.1 Million)	95
11.	IP Solution Mix Compared to Mixes Determined by Ranking (Budget Ceiling = $136.4 Million)	96
12.	The Opportunity Cost of Ranking (Range Analysis)	102
13.	An Analysis of the LP Solution Mix	108
14.	Results of the ROI Model (Budget Ceiling = $73.1 Million)	112
15.	Results of the ROI Model (Budget Ceiling = $136.4 Million)	113
16.	Results of Sequential GP Model (Budget Ceiling = $73.1 Million)	116

Table Page

17. Results of Sequential GP Model (Budget Ceiling = $136.4 Million) 117

18. PIF Project Data 131

19. IP and Ranked Solution Mixes (Budget Ceiling = $73.1 Million) 162

20. IP and Ranked Solution Mixes (Budget Ceiling = $136.4 Million) 167

21. Cash Flow Data on Mixes Selected by IP and Ranking (Budget Ceiling = $73.1 Million) . . . 172

22. Cash Flow Data on Mixes Selected by IP and Ranking (Budget Ceiling = $136.4 Million) . . 173

23. Multiple-criteria Solution Mixes 174

24. Cash Flow Data on Multple-criteria Models . . . 179

LIST OF FIGURES

Figure Page

1. Overview of Methodology 60

2. Software Development and Verification 61

3. Database Development and Verification 62

4. Mix Selection by Ranking 63

5. Mix Selection by IP 64

6. Ranked and Single-criterion Solution Mixes Compared 65

7. Ranked and Multiple-criteria Solution Mixes Compared 66

8. Cross-over Analysis 82

9. NPV of Solution Mixes Compared (Budget Ceiling = \$73.1 Million) 98

10. NPV of Solution Mixes Compared (Budget Ceiling = \$136.4 Million) 99

11. The Opportunity Cost of Ranking (Budget Ceiling = \$73.1 Million) 100

12. The Opportunity cost of ranking (Budget Ceiling = \$136.4 Million) 101

13. The Average Opportunity Cost of Ranking (Range Analysis) 103

14. Cross-over Analysis (Budget Ceiling = \$73.1 Million) 105

15. Cross-over Analysis (Budget Ceiling = \$136.4 Million) 106

ACKNOWLEDGEMENTS

The views, opinions and findings contained in this study are my own and should not be construed as an official policy, decision, or position of the Department of Defense, Air University, or Air Force Institute of Technology. There are, however, many individuals who have contributed to this study, and I would be remiss if I failed to acknowledge them.

First and foremost, I express my love and appreciation to my wife and eternal companion, Carol. In the past three years of my studies, she has done everything from bringing our youngest daughter into the world to changing the oil in our lawnmower. Without Carol's constant encouragement, confidence and support, this study could not have been accomplished.

I am also greatful for the support and advice of my dissertation committee. Professor James F. Brown, Jr. has served as my chairman and guided me with patience and great skill. The prompt and useful comments of Professors Richard W. Metcalf and Thomas E. Balke are greatly appreciated. I am also indebted to Professors Thomas Iwand and Jon Nance who provided encouragement and advise in the initial stages of the study.

The assistance of other individuals is also appreciated. Mr. Robert K. Ackard, of the Defense Productivity Program Office, graciously provided the necessary data and background information to conduct the study. Mr. Brian Loseke, of IBM Corporation, provided the necessary software.

Finally, I express my gratitude to the United States Air Force and to the Air Force Institute of Technology for supporting and sponsoring my graduate studies.

CHAPTER 1

INTRODUCTION

Background

The Productivity Investment Fund (PIF) program is an ongoing Department of Defense (DoD) capital investment program that involves capital rationing. Capital rationing is a subset of capital budgeting where funds for financing long-term investment projects are limited by one or more budget ceilings. Capital rationing is actually a decision problem with four, fairly distinct stages involving (1) identifying projects closely linked to the organization's strategic objectives, (2) developing project information and cash flow estimates needed for analysis and selection, (3) selecting the portfolio of projects for funding through the use of one or more economic and possibly noneconomic criteria, and (4) evaluating the performance of approved projects (Pinches, 1982). While the PIF capital rationing problem involves all four of these phases, this study is primarily concerned with the selection phase.

The objective of the PIF program is essentially economic. The program is actually part of a larger DoD program, the Productivity Enhancing Capital Investment (PECI) program, designed to encourage economy and efficiency in the

DoD through productivity enhancing capital investments. The DoD clearly has noneconomic objectives that dominate economic objectives. Maintaining a defense system that effectively deters nuclear war cannot be dominated by financial priorities. Once noneconomic objectives are achieved (or alternatives that satisfy noneconomic objectives have been identified), economic objectives may then be considered. The DoD has long been concerned with cost effectiveness analysis, termed "economic analysis" (Fisher, 1971). The PIF capital rationing decision is but one type of economic analysis.

Because the objective of the PIF program is economic, projects are evaluated for funding using economic criteria. The current selection method employs ranking. Ranking is very easy to apply and is widely used in both the private and public sectors (e.g., Farragher, 1986; Guranani, 1984). But like all heuristics, ranking has several limitations that may result in a suboptimal economic choice: the net present value (NPV) of the portfolio of projects selected by ranking may not be maximized. The limitations of ranking will be described in detail in chapter 2, but generally involve (1) the existence of multiple, usually contradictory selection criteria, (2) multi-period budgets and (3) projects that are indivisible and/or interdependent. Sometimes the portfolio identified by ranking is optimal, but one can never be certain without evaluating all possible combinations of projects. In the language of Nobel laureate Herbert

Simon (1957), ranking is clearly a "satisficing" approach to the capital rationing problem.

Unlike the ranking approach, mathematical programming (MP) is an exact approach in which an objective function containing one or more desired criteria is optimized (maximized or minimized) subject to a series of constraints. For the capital rationing problem, one set of constraints describes the budget ceiling(s). MP is not as widely used as ranking, perhaps because it has its own theoretical issues and practical limitations involving (1) the choice of the discount rate to use in formulating the objective function, (2) the existence of multiple objectives in the capital rationing decision problem, (3) the non-deterministic nature of the data, and (4) the large numbers of competing projects. These issues and limitations make the successful application of MP to the PIF problem in particular and to any large-scale capital rationing problem in general extremely uncertain. Thus, exploring the feasibility of applying MP to the PIF program is a necessary and important task.

Statement of Problem

The purpose of this study is to explore the application of MP to the PIF program. Specifically, is the application of MP to the PIF program (1) appropriate and (2) feasible? MP is considered appropriate if (a) the intent and nature of the PIF program are consistent with an optimizing approach to project selection, and (b) there is sufficient economic incentive to justify the use of an optimizing instead of a heuristic approach to project selection. The question of feasibility can only be addressed by formulating and running a suitable MP model of the PIF capital rationing problem. A suitable MP model requires a careful consideration of the theoretical and practical limitations of MP both generally and in the context of the PIF program.

Objectives

To address these questions this study has the following objectives:

1. Review the purpose and history of the PIF program.
   a. Are the intent and nature of the PIF program consistent with an optimizing approach?
   b. Is there economic incentive to use MP instead of ranking?
2. Develop and run appropriate MP formulations of the PIF capital rationing problem.
   a. Review the theoretical and practical limitations of MP as discussed in the literature.
   b. Identify possible economic savings.

Contributions

This study is expected to make the following contributions. First, substantial dollar savings may be realized by the DoD. Simulation studies (e.g., Forsyth and Owen, 1981) suggest that marginal savings are likely when MP is used instead of ranking. In the multi-million dollar PIF program the marginal savings may amount to millions of dollars. Both the President and the public have expressed concern over waste in government. President Reagan has set a goal of twenty percent productivity improvement in the Federal government by 1992 (Executive Order 12552, 25 February 1986). Improving the effectiveness of the PIF program is consistent with this goal. While savings measured in a few million dollars may seem insignificant against a DoD budget now exceeding $300 billion, in an era when the public is concerned with an overpriced public wrench or ash tray (e.g., Payne, et al., 1985; Mann, 1985), achieving savings potentially valued in the millions of dollars is important.

Second, there has been little applied research in the area of capital budgeting/rationing, especially in management accounting. This is unfortunate, because management accounting is an appropriate discipline for such research. In a review of published management accounting research from 1926 to 1983, for example, Klemstine and Maher (1983) observed that of thirty-four articles on capital budgeting, not one involved an actual capital budgeting problem: twenty-five were classified "a priori"; seven were simulations; one was a survey; and one was a lab experiment. Even in the finance and engineering economics literature, references to capital budgeting problems involving actual data are rare. The majority of the work has been theoretical, involving (1) the development of sophisticated MP algorithms and models for capital rationing and (2) persistent, often confusing academic debates concerning issues such as discounting, uncertainty and multiple objectives. The scarcity of applied research in this area may explain why the more heuristic approaches to the capital rationing decision problem persist despite their known theoretical weaknesses. Reporting the successful application of MP to real life capital rationing problems is needed.

Third, this study has relevance beyond the PIF program. The issues and practical concerns to be addressed are quite general to the capital rationing problem as experienced in both the public and private sectors. For example, the discount rate issue applies to either sector and has been debated in the academic literature for many years. Many authors claim that the MP formulation developed by Weingartner (1963) is incorrect because it uses a discount rate that is independent of the projects competing for funding. The discount rate issue is important because it is central to the proper specification of the objective function. There is a need to clarify and interpret these debates, characterized by Weingartner (1977, p. 1416) as a "Tower of Babel." It is believed that placing these issues in the context of an actual problem serves that need. In addition, survey research (e.g., Farragher, 1986; Guranani, 1984) reveals that large-scale, multiple-criteria capital rationing problems are common. The PIF capital rationing problem is no exception. Reporting the results of applying MP to the PIF problem will indicate what can be done for other similar problems.

In summary, the contributions of this study are largely practical. Accounting is a practical discipline. Silhan (1982, p. 38) defines management accounting as "applied research." In recent years, however, management accounting research has been somewhat preoccupied with information economics and agency theory. Kaplan (1984, p. 407) is generally critical of this line of management accounting research, observing that it is "largely devoid of references to actual organizations." Demski and Kreps (1982, p. 118) observe that accounting researchers often have opportunities to experience management decision problems <u>in context</u>, and challenge accountants to share this special knowledge in research and articles. This study is in the spirit of the Kaplan-Demski-Kreps challenge and begins to fill the void of applied capital budgeting research identified by Klemstine and Maher.

Potential Limitations

This study has at least two potential limitations. First, it is primarily concerned with the selection phase of the capital budgeting decision problem. Unfortunately, this is not unusual. From survey research, Gitman and Forrester (1977) report that managers consider the most difficult and important stages of capital budgeting to be project identification and cash flow estimation. Most academic literature (including this study) has concentrated on the selection phase. There is clearly a need to extend management accounting research to the other phases of capital budgeting. Gordon, Larcker and Tuggle (1979) and Pinches (1982) have made some progress in this area, but more work is needed.

Second, it is recognized that the MP approach to the capital budgeting problem is an exact solution in an imperfect world. Optimization science is strongly normative. In the spirit of Simon's "satisficing," and Lindblom's "muddling through," the solution identified by MP may simply not be implementable given institutional constraints and policies requiring compromise and accommodation to special interests. In the context of the PIF program, Congress has final authority to approve or disapprove funding for any particular PIF project. The position of this study is that the DoD has a responsibility to identify and present Congress with the best feasible portfolio of PIF projects. This is consistent with the intent of the PIF program. If some other portfolio is preferred by Congress, then at least the opportunity cost of enforcing a noneconomic choice will be known.

Organization

The remaining chapters are organized to follow the objectives of this study. Chapter 2 examines the purpose and history of the PIF program and describes the limitations of selection strategies that employ ranking. The purpose is to establish the appropriateness and desirability of applying MP to the PIF capital rationing problem. Chapter 3 describes the general MP approach. The strengths and limitations of MP are examined to establish a suitable MP formulation. Chapter 4 describes the methodology for exploring the feasibility question. General procedures for dealing with MP limitations in the context of the PIF program are described and defended; specific procedures regarding hypothesis testing, sensitivity analysis, and model parameter specification are also described and defended. Chapter 5 describes and analyzes the results of the feasibility tests. Chapter 6 summarizes the results and suggests some extensions for further research.

CHAPTER 2

THE PRODUCTIVITY INVESTMENT FUND (PIF) PROGRAM AND THE LIMITATIONS OF RANKING

The purpose of this chapter is to establish the appropriateness and desirability of applying mathematical programming (MP) to the Department of Defense (DoD) PIF program. A review of the origin and context of the PIF program establishes that an optimizing approach to project selection is appropriate. A review of the limitations of ranking suggests that the method is inconsistent with the PIF program's intent: the portfolio of projects selected by ranking almost certainly fails to maximize dollar savings to the DoD. Material dollar savings are likely if an exact approach to project selection, MP, is used instead of ranking. The chapter concludes with a consideration of the relationship between optimizing and heuristic approaches.

The PIF Program

As explained in chapter 1, the PIF program is part of the DoD's Productivity Enhancing Capital Investment (PECI) program. The PECI program was established in 1975 to increase productivity and efficiency in the DoD through capital investments. Investment projects that substituted labor for capital were especially attractive because personnel costs were (and continue to be) a significant portion of total defense costs. The DoD has long recognized the importance of achieving economy and efficiency. In fact, it was the leader in initiating the Planning, Programming and Budgeting System (PPBS) in the 1960s (Keen, 1977, p. 36). However, as late as 1975 the use of capital investments to enhance productivity was generally impaired by the perceived higher priority of mission, regulatory and quality-of-life requirements (General Management Systems, 1986, p. 4):

> . . . investments for readiness, such as the establishment of a depot or field support capability for a new aircraft or ship entering the inventory or the building of aircraft shelters in a forward area, have the highest priority. The next priority is often those investments or expenditures required by law to implement various national programs, such as EEO, OSHA and EPA. Close behind may be the filling of shortfalls in family housing or enlisted personnel barracks. Modernization of facilities, or investments in facilities and equipment to improve productivity have tended to be assigned low priority and to be deferred or deleted. The usual rationale for deferment or deletion is that the work will still be accomplished, albeit less efficiently.

In addition, when low cost, fast-payback projects were approved, it often took two years to receive funding. Initiating organizations had little incentive to identify such projects, particularly when it could take more time to get a project funded than for the project to pay for itself. The need for a fund specifically dedicated to productivity enhancing capital investment projects thus became apparent to DoD officials.

The PECI program has three funding strategies. Each strategy (also referred to as a fund or a program) has different qualification criteria involving investment ceilings and payback periods, and focuses on different opportunity targets. Payback is generally achieved through reduced operating and support costs and through labor reductions resulting from the investment. As an incentive to identify PECI projects, the financial and labor benefits from funded PECI projects can be used to support the valid, unfunded requirements of the submitting organizations. The three funding strategies are summarized in table 1:

TABLE 1

THE PRODUCTIVITY ENHANCING CAPITAL INVESTMENT PROGRAM

	Funding Strategies		
Qualifying Criteria	PEIF	PIF	CSI
Investment floor	$ 3,000	$100,000	$100,000
Investment ceiling	$ 99,999	None	None
Payback period (maximum)	2 years	4 years	5 years

The first strategy, Productivity Enhancing Investment Fund (PEIF), is for projects that cost less than $100,000 and have payback periods of two years or less. PEIF funds ($32.5 million in Fiscal Year 1987) are budgeted by each DoD component annually, but without identification to specific projects. By not linking the funds to specific projects, qualified projects can be quickly financed from each DoD component's PEIF "drawing account," often within ninety days from project approval. PEIF funds are specifically directed to the smaller projects often proposed by the worker or first-line supervisor.

The second strategy, PIF, is for projects that cost more than $100,000 and with payback periods of four years or less. Into this fund, the Office of the Secretary of Defense (OSD) currently programs about $176 million annually and competitively selects projects submitted from DoD components (e.g., the United States Army, Navy, Air Force, Marines). Funds for selected projects are allocated to the DoD components and actual funding is through the normal budget process. PIF funds are targeted at major improvements that typically involve facility construction or major equipment acquisitions.

The third strategy, Component Sponsored Investment (CSI) program, is for projects that cost more than $100,000 and with payback periods of five years or less. This fund ($45.8 million in Fiscal Year 1987) is allocated to each DoD component. Each DoD component is free to select projects based on its own criteria. The intent of the CSI program is to achieve some flexibility in supporting individual DoD component priorities. Like the PIF program, the CSI program targets major improvements. Projects disapproved by OSD in the PIF program may be funded by the sponsoring component through the CSI program.

Of the three PECI programs, the PIF program is the most competitive in the sense that all qualifying PIF projects cannot be funded: the total cost of the PIF projects exceeds the total funds available. From Fiscal Years 1982 to 1986, for example, 276 of the 794 submitted PIF projects were approved by OSD for funding. The total cost of the approved projects was $595 million; the total cost of the submitted projects was $2,138 million.

Tables 2 and 3 detail the PIF submission and approval history (General Management Systems, 1986). For the last few years about two hundred PIF projects have competed for funding annually. Of these, the number of projects that can be approved subject to the budget ceiling ranges from about fifty to seventy each year.

The principal reason for not selecting all projects is inadequate funds (General Management Systems, 1986, p. 34). By the time the projects have reached OSD, most have been subjected to exhaustive qualitative and quantitative reviews at Command, Major Command and installation levels. A review typically involves circulating the proposed PIF project through a number of functional staff organizations to assess the project's feasibility, reasonableness, accuracy, and compliance with regulations.

The Air Force review and screening process is typical. A project originating at a base is reviewed by the Management Engineering Team (to validate the estimated manpower savings), the Comptroller (to validate the economic analysis), and any other organization with expertise related to the project (e.g., civil engineering, data processing,

TABLE 2

PIF PROJECTS SUBMITTED BY DOD COMPONENTS

DoD Component	FY82	FY83	FY84	FY85	FY86	Total
Army	25	61	79	99	123	387
Navy-Marine	42	41	78	46	28	235
Air Force	11	14	40	35	45	145
Defense Agencies	8	2	9	6	2	27
Total	86	118	206	186	198	794
Budget ceiling ($M)	90	121	129	136	139	615
Funds requested	279	393	639	299	528	2138

TABLE 3

PIF PROJECTS APPROVED BY OSD

DoD Component	FY82	FY83	FY84	FY85	FY86	Total
Army	13	33	17	15	41	119
Navy-Marine	23	22	18	11	9	83
Air Force	7	8	14	18	15	62
Defense Agencies	4	2	2	2	2	12
Total	47	65	51	46	67	276

medical, logistics, supply, communications, administration). Every effort is made to identify and resolve problems and questions before submitting the project to Major Command. At Major Command, a virtually identical review process occurs. PIF projects are generally not submitted to Headquarters Air Staff until all problems and questions are resolved. Most projects are revised before they are sent to Air Staff. This can involve anything from making small revisions based on telephone conversations, to returning the project for a major revision. At Air Staff, each project is reviewed again for reasonableness and accuracy by a thirty-member productivity committee, comprised of members from most functional areas in the Air Force. When the projects arrive at OSD, they are separated by function (e.g., aircraft maintenance, automatic data processing, military construction, medical) and forwarded to the appropriate OSD functional manager for a final screening.

Once this extensive screening and review process is completed, the number of projects remaining still exceeds the budget ceiling. Accordingly, OSD must select the projects based on priorities established by regulation. The following policies from the DoD regulation that established the PECI program (DoDI 5010.36, Section E) are relevant to the selection criteria:

> Policy 4. Capital-labor substitution through productivity enhancing investment and leasing actions shall be exploited as a primary means for improving the labor productivity of defense organizations.

Policy 6. Top priority shall be given to those potential investments that amortize in the shortest period of time and those with the highest potential internal rate of return (IRR) on investment or highest net present value (NPV). For projects having identical IRRs or NPVs, proposals will be ranked for financing in the following order of priorities:

6a. Projects that save whole personnel spaces or authorizations that can be reapplied at the local level.

6b. Projects that save whole personnel authorizations that cannot be reapplied to perform other valid requirements at the local level, but can be reallocated to other activities as priorities dictate.

6c. Projects that avoid overtime personnel costs or release work hours and personnel to be reapplied to other uses.

6d. Projects that save consumable materials.

6e. Projects that produce other cost savings which can be reapplied to valid unfinanced requirements.

The Defense Productivity Program Office (DPPO), the OSD organization with overall responsibility for the PECI program, has operationalized these selection criteria by employing three economic indicators: IRR, Return on Investment (ROI), and investment cost per manpower space saved (CPM). Only IRR captures the time value of money. The other measures are based on undiscounted dollars. IRR is the discount rate that equates economic benefits to costs. Alternatively, it is the rate that makes the NPV of the net cash flow for a given project equal to zero. A formula for IRR consistent with these definitions is:

$$\sum_{t=0}^{T} (\text{Savings}(t) - \text{Costs}(t)) / (1+r)^{*}\text{EXP}(t) = 0 \qquad (1)$$

where "T" is the economic life of the project; "t" is the time period; "Savings(t)" and "Costs(t)" are the cash inflows and outflows, respectively, in period t of the project; and "r" is the IRR of the project expressed as a decimal. All cash flows are assumed to occur at the end of each year and are adjusted to constant dollars using DoD indices. (The DPPO presently does not calculate IRR correctly. This problem will be discussed in chapter 4.)

Using the same notation, the formulas used by the DPPO for ROI and CPM are:

$$\text{ROI} = \sum_{t=0}^{T} \text{Savings}(t) \Big/ \sum_{t=0}^{T} \text{Costs}(t) \qquad (2)$$

$$\text{CPM} = \sum_{t=0}^{T} \text{Costs}(t) \Big/ \sum_{t=0}^{T} \text{Manpower Savings}(t) \qquad (3)$$

"Manpower Savings" are manpower spaces that can be reassigned or deleted if the investment project is approved. For example, clerks or secretaries assigned to an office may be more productively used elsewhere if a new office system, say a word processor, is purchased. If there are no manpower savings from a particular investment project, the DPPO sets the CPM criterion to an arbitrarily high value, indicating a relatively unattractive project from a "manpower saved" viewpoint.

The DPPO capital rationing strategy employs these three indicators to rank and select projects for funding. After the indicators are calculated, the projects are ranked three times, once for each indicator, producing three ranked lists. (The projects are assigned numbers sequentially to reflect relative attractiveness. The most attractive project receives the rank of one; the second most attractive project receives the rank of two, etc.) Each indicator receives equal weight. The ranked lists are next summed and re-ranked to produce the final listing. For example, a project with a rankings of two (based on IRR), three (based on ROI) and seven (based on CPM) would receive a composite ranking of twelve. Ties in the final listing are broken by the project with the largest IRR. This listing is then used to select projects in ascending order until the budget ceiling is exhausted. The partial funding of projects is currently not an option considered by the DPPO in the PIF program. Accordingly, marginal projects with investment costs too large are by-passed to more fully utilize the budget. For example, if the thirty-fifth project in the final listing cannot be completely funded because its cost exceeds the remaining funds in the budget, the project is skipped and project thirty-six is considered for funding.

Once the projects are selected, the DPPO will issue a Program Budget Decision to each DoD component. The DoD components will then add the appropriate money to their Service Budget Requests. Once Congressional approval is received, the funds are appropriated. The entire cycle takes from one to two years from when the DPPO first receives the projects to when funds are appropriated.

In summary, the intent of the PIF program is to achieve economy and efficiency. The program was established because higher priority objectives were preventing economically attractive projects from being funded. More PIF projects are submitted than can be funded. Accordingly, the projects must compete for the scarce resources available. After an extensive screening process conducted at several organizational levels to evaluate project reasonableness and accuracy, the project selection decision becomes completely objective, using the DPPO ranking method described above. A review of the DoD regulation governing the PIF program suggests that maximizing dollar savings is an appropriate objective; the use of IRR or NPV is specified.

The DPPO ranking method has certain limitations that make its continued use inconsistent with the intent of the PIF program. The method almost certainly fails to maximize dollar savings. First, the use of multiple criteria, some of which are noneconomic, likely results in a suboptimal mix of projects. The CPM and ROI criteria do not employ discounted cash flow concepts, and are therefore suspect given the PIF program's economic objective. Second, single-criterion ranking may also fail to identify an optimal economic mix of projects. The limitations of ranking are described next.

Limitations of Ranking

There is an extensive literature demonstrating the problems with ranking-based strategies (e.g., Lorie and Savage, 1955; Solomon, 1956; Hirshleifer, 1958; Weingartner, 1963; Teichroew, Robichek and Montalbano, 1965; Bernhard, 1971; Bussey, 1978; Clark, Hindelang and Pritchard, 1979; Lumpy, 1984). In general, if (for any reason) two or more investment projects must be compared, where not all of the projects can be accepted, then some selection strategy is necessary. Ranking (popularized by Dean, 1951) is one strategy, but it has serious limitations. Perhaps its major limitation involves the appropriate selection criterion.

Many criteria have been proposed. Some are clearly deficient. For example, using payback as a direct criterion for project selection is incorrect because it ignores the cash flows of the project beyond the payback period (Weingartner, 1969). ROI and CPM are deficient because they ignore the time value of money. Bernhard (1971) reviewed eight criteria or indices that use discounting, and demonstrated that all were equivalent variations of IRR, NPV or a benefit-cost ratio. When only these three criteria are applied against the same group of competing projects, conflicting or inconsistent rankings can still occur (Lorie and Savage, 1955; Bernhard, 1962; White and Smith, 1986).

Given the problem of inconsistent rankings, which investment criterion and resulting portfolio of projects is correct? Conflicting rankings occur due to (1) differences in reinvestment assumptions implicit in the criteria used, and (2) size/timing differences between projects (Schwab and Lusztig, 1969). One reason for inconsistent rankings involves the implicit assumption regarding the reinvestment of cash flows under each criterion over the life of the project. NPV-based ranking implicitly assumes reinvestment at the rate used to calculate NPV; IRR-based ranking implicitly assumes reinvestment at the project's IRR. Finance literature (e.g., Keane, 1974; Clark, Hindelang, Pritchard, 1979) generally condemns the IRR reinvestment assumption as unrealistic and recommends the NPV criterion for nonrationed, mutually exclusive projects.

When capital is rationed, neither NPV-based nor IRR-based ranking is appropriate because neither reflects a project's economic worth relative to the constrained resource (e.g., the budget ceiling) used. To remedy this problem, benefit-cost ratios are sometimes recommended (e.g., Quirin and Wiginton, 1981). Once the ratios are calculated and arrayed in descending order, the projects are accepted until the budget ceiling is exhausted. There are several forms of discounted benefit-cost ratios. The more common ones involve whether or not the numerator is stated net of cash outflows. The terms "profitability index" (Lindsay and Sametz, 1963) and "excess present value index" (Horngren and Foster, 1987; Moore and Jaedicke, 1963) have been used to describe either variation in the literature. In this study, profitability index (PI) is defined as the ratio of net discounted benefits (NPV) divided by discounted costs, and excess present value index (EPI) is defined as the ratio of gross discounted benefits divided by discounted costs.

The use of benefit-cost ratios can also result in suboptimal economic choices. The basic problem is called "lumpiness." When ratio-based ranking is used, a project with a large cost (lumpy) may displace a group of smaller projects which, if accepted collectively, may have a larger NPV (Bussey, 1978, p. 266). In addition to the lumpiness effect, Weingartner (1963) has demonstrated that ratio-based ranking strategies can fail to identify the optimal economic mix when projects are indivisible and/or capital is rationed in more than one period. In the PIF program, all projects are assumed indivisible, and some projects do require investment costs in the outyears.

In summary, ranking strategies are often employed when capital investment projects must be compared with each other and cannot all be accepted. For example, the projects may be mutually exclusive, mutually dependent, indivisible, or subject to a budget ceiling in one or more periods. Under these conditions ranking strategies using NPV, IRR or various kinds of benefit-cost ratios can conflict and do not always identify the optimal economic mix. The PIF program has many of the conditions that make ranking inappropriate. In addition, the selection method employs multiple, theoretically deficient criteria. Accordingly, the mix of projects currently selected for funding in the PIF program is probably suboptimal.

Although the mix of projects is probably suboptimal, there may not be sufficient economic incentive to use or even investigate the use of MP. The relative effectiveness of capital rationing strategies with each other (White and Smith, 1986) and with MP approaches (Para-Vasquez and Oakford, 1976); Forsyth and Owen, 1981) have been compared in simulation studies. Results indicate that different ranking strategies do result in different mixes and do identify mixes inferior to the optimal mix determined by MP. Forsyth and Owen (p. 219) observed that the optimal mix was only marginally better than mixes selected by ranking:

> The simulation results showed that the relative difference between the two sets of investment candidates was less than two percent in seventeen of nineteen cases.

However, in the PIF program, marginal savings are measured in millions of dollars. For example, in Fiscal Year 1985, the total NPV of the projects selected for funding in the PIF program is $778.3 million. Two percent of this value, $15.6 million, is the expected savings from using an exact approach instead of a heuristic approach to project selection. Is this magnitude of expected savings material to a DoD budget now exceeding $300 billion? If public concern about discovered over-pricing abuses in the DoD is any measure of materiality, then savings in the millions of dollars is material, and an optimizing approach is appropriate.

Conclusion

In conclusion, a somewhat philosophical observation regarding the relationship between rational, optimizing approaches (MP) and satisficing, heuristic approaches (ranking) is needed. Simon (1969, p. 64) has summarized the theory of satisficing as follows:

> In the real world we usually do not have a choice between satisfactory and optimal solutions, for we only rarely have a method of finding the optimum. . . . We cannot, within practicable computational limits, generate all the admissible alternatives and compare their relative merits. Nor can we recognize the best alternative, even if we are fortunate enough to generate it early, until we have seen all of them. We satisfice by looking for alternatives in such a way that we can generally find an acceptable one after only moderate search.

Understood correctly, heuristics should be only temporary devices, necessary to reflect the descriptive realities of human capabilities and relationships in organizations. If those human limitations are eventually extended, say by technology or research, then the heuristic should be either modified to reflect the new reality or abandoned completely. In the case of capital rationing, ranking is clearly a heuristic approach reflecting the computational abilities of the 1950s when it was popularized by Joel Dean. The optimal solution mix could not then be identified because it was not "within practicable computational limits." The MP algorithms and computers now widely available suggest that the ranking heuristic should be re-evaluated. If an exact approach is feasible, any heuristic approach is only second best. As Ackoff and Sasieni (1968, p. 443) have stated:

> Satisficing is usually defended with the argument that it is better to produce a feasible plan that is not optimal than an optimal plan that is not feasible. This argument is only superficially compelling. Reflection reveals that it overlooks the best feasible plan. Optimality can (and should) be defined so as to take feasibility into account, and the effort to do so forces us to examine the criteria of feasibility that are seldom made explicit in the satisficing process.

This chapter has described the PIF program and the limitations of ranking. The intent of the PIF program is consistent with an optimizing approach. The current selection method is not an optimizing approach and is suspect given the existence of multiple criteria, rationing, indivisibilities, multiple-budgets and theoretically deficient criteria. Material economic savings are likely if MP is feasible. The next chapter discusses the feasibility question.

CHAPTER 3

THE MATHEMATICAL PROGRAMMING APPROACH AND ITS LIMITATIONS

The previous chapter established that an optimizing approach to project selection in the Department of Defense (DoD) Productivity Investment Fund (PIF) program is appropriate. Ranking is not an optimizing approach and has limitations which can result in suboptimal economic choices. Mathematical programming (MP) is an optimizing approach and can overcome the limitations of ranking. However, there are theoretical issues and practical limitations with the MP approach, including (1) the choice of the discount rate to use in formulating the objective function, (2) the existence of multiple criteria or objectives in the capital rationing decision, (3) the nondeterministic nature of the data, and (4) the large number of competing projects. These issues and limitations make the successful application of MP to the PIF capital rationing problem uncertain. Investigating the feasibility of applying MP to the PIF program is desirable because material dollar savings are likely if projects are selected by MP rather than by ranking. This chapter explores the feasibility of applying MP to the PIF capital rationing problem. The general MP approach to capital rationing and the limitations of MP are described by reviewing the extensive academic literature treating this topic.

The Mathematical Programming Approach

Exhaustive Enumeration

If the number of competing projects is relatively small, the optimal economic mix may be determined by exhaustive enumeration: consider all possible combinations and select the one that maximizes net present value (NPV) while not violating any budget constraint. Evaluating every combination is necessary to assure that a larger project is not selected over a group of smaller projects with a larger NPV (the lumpiness effect described in chapter 2, p. 23).

As the number of competing projects increases, the number of combinations grows exponentially. In general, the number of possible combinations (potential solutions) is equal to 2*EXP(n), where n is the number of competing projects (Bussey, 1978, p. 270). Thus, there are only sixteen possible combinations for four competing projects, thirty-two combinations for five competing projects, and so on. Obviously, a solution strategy involving a search of all combinations rapidly becomes impractical. For example, 186 projects competed for funding in the PIF program in Fiscal Year 1985. An exhaustive enumeration approach would require evaluating 2*EXP(186) portfolios.

While the number of combinations requiring evaluation can be astronomical, it is possible to establish upper and lower limits on the number of projects in the optimal mix through the use of a heuristic. The maximum number of projects in the optimal mix is no greater than the number of projects that can be selected in ascending order by cost. The minimum number of projects in the optimal mix is no less than the number of projects that can be selected in descending order by NPV. While this simple heuristic does limit the number of combinations requiring explicit evaluation, the number of feasible combinations remaining may still be too large for an exhaustive search strategy. Even with a computer, the exhaustive search procedure is not practical, and a more efficient method that does not require an explicit evaluation of all possible combinations is required. MP algorithms have thus been applied to the capital rationing problem to more efficiently arrive at the optimal solution.

Early MP Algorithms

Linear programming (LP) is perhaps the most widely used MP approach to the capital rationing problem. Danzig (1963), generally recognized as the pioneer of LP (Lee, et al., 1985, p. 25), developed the simplex algorithm during World War II. The simplex algorithm has proven to be extremely efficient in large-scale problems with thousands of continuous decision variables (IBM, 1979, p. 43). When the decision variables are not continuous, integer programming (IP) is used. When the decision variables can only take on values of zero or one, zero-one programming is used.

There are several basic IP algorithms. Gomory (1958) developed a technique that modifies the standard LP formulation by adding cutting planes as additional constraints to reduce the number of feasible combinations requiring evaluation. Land and Doig (1960) developed a branch-and-bound method for zero-one programming. Finally, in the implicit enumeration method, developed by Balas (1965), Glover (1965) and Geoffrion (1967), large numbers of solutions are excluded from explicit evaluation without excluding the optimal solution (Gue, Liggett and Cain, 1968).

Regardless of the type of programming involved, a key advantage of the MP approach is its ability to efficiently arrive at the optimal solution without having to explicitly evaluate every combination. When applied to capital rationing, the lumpiness problem is directly resolved because every feasible combination is evaluated, either explicitly or implicitly.

Weingartner's MP Formulation

Weingartner (1963) was one of the first to suggest the application of MP to the capital rationing problem. Weingartner's original model is formulated as follows:

$$\text{Maximize} \qquad NPV = \sum_{i=1}^{N} NPV(i)X(i) \qquad (4)$$

Subject to

$$\sum_{i=1}^{N} C(t,i)X(i) <= B(t) \quad \text{for } t = 1, 2, \ldots, T \qquad (5)$$

$$X(i) = \{0,1\} \quad \text{for } i = 1, 2, \ldots, N \qquad (6)$$

Where N is the number of competing projects
X is the project ("choice variable")
C is the cash outflow in period t for project i
B is the budget ceiling for periods t = 1 to T
T is the number of budget constraints

In addition to resolving the lumpiness problem, this formulation overcomes other limitations of ranking. In equation 6, project indivisibility is enforced, where each project must either be completely accepted, X(i) = "1", or completely rejected, X(i) = "0". More constraints can be added to express relationships between projects and to satisfy nonfinancial restrictions. For example, if projects i and j were mutually exclusive, this relationship may be expressed as X(i) + X(j) = 1. In general, if "J" is a set of mutually exclusive projects to be considered, this condition can be enforced using the integer MP formulation in at least two ways:

$$\sum X(i) <= 1 \qquad \text{for all } i \text{ in } J \qquad (7)$$

$$\sum X(i) = 1 \qquad \text{for all } i \text{ in } J \qquad (8)$$

In equation 7, at most one project from set J can be accepted; in equation 8, one project from set J must be accepted. If project i was contingent on the adoption of project j, this relationship could be expressed as follows:

$$X(i) - X(j) = 0 \tag{9}$$

Also, a nonfinancial objective of achieving some minimum level of manpower reductions can readily be added as a constraint. Finally, as indicated by equation 5, the formulation allows for multi-period rationing.

Though this formulation can overcome many of the limitations of the ranking strategy, the MP approach is not without its own limitations. First, a discount rate must be specified before NPV can be calculated. Second, only *one* criterion, NPV, is being maximized. Third, the model is deterministic. Fourth, integer restrictions create computational efficiency difficulties. Each of these limitations is described next, beginning with the discount rate.

The Limitations of MP

The Discount Rate Limitation

Hard Rationing

As indicated in table 4, the discount rate question hinges on the exact meaning of capital rationing. Capital rationing is often loosely described as either "hard" or "soft" (Carleton, 1969). In hard rationing, the organization has no access to external markets for either borrowing or lending. The budget ceiling is inflexible, nondiscretionary and imposed by forces external to the organization. Hirshleifer (1958) asserts that in the private sector hard rationing is probably a rare, short-term phenomenon. Survey research generally confirms this (Finn, 1973; Gitman and Forrester, 1977). In the public sector, hard rationing is probably more common, where compliance with budgeted levels of spending is often a legal constraint. Also, under the zero-based budgeting concept, common in nonprofit organizations, every dollar of the budget must be justified. According to Zimmerman (1976), both underspending and overspending can result in reduced future budgets. Meeting the budget ceiling exactly is an understandable objective for public organizations.

TABLE 4

THE APPROPRIATE DISCOUNT RATE

Sector	Hard Rationing	Soft Rationing
Private	Indeterminate ex ante	Cost of capital
Public	Indeterminate ex ante	Social cost of capital

When hard rationing does occur, the appropriate discount rate to use in establishing the objective function is not the firm's cost of capital. Instead, the rate is dependent on the group of projects competing for funding and is determined by the marginal project in the solution mix (Baumol and Quandt, 1965). The correct rate is an opportunity cost or shadow price that results from the analysis. Since this rate (or rates) is not known before the solution mix is determined, and since the solution cannot be determined until the rate-dependent objective function can be established, the original Weingartner formulation of the capital hard rationing problem appears to be inappropriate.

Concern over the discount rate dilemma in capital hard rationing has generated extensive discussion in the literature. Baumol and Quandt (1965) were the first to challenge Weingartner's formulation, and changed the model in several ways. To overcome the discount rate problem, Baumol and Quandt replaced the NPV maximand with owners' utility for cash withdrawals. While this idea may indeed be sound on theoretical grounds, it can be criticized as impractical due to the required utility assessment.

Elton (1970) and Myers (1972) suggest that the discount rate dilemma exists only when both the firm and its owners are excluded from market opportunities. Specifically, if owners have market exchange opportunities, the firm's cost of capital "serves perfectly well as the firm's external discounting criterion" (Myers, p. 92).

Finally, a number of authors (Lusztig and Schwab, 1968; Whitmore and Amey, 1973; Atkins and Ashton, 1976; Bradley and Frey, 1979; Bradley, Frank and Frey, 1978; Freeland and Rosenblatt, 1978; Oakford, Salazar and Bhimjee, 1979; Hayes, 1984, 1985; and Baum, 1984) have attempted to prove or disprove the nontrivial existence of discount factors derivable from the shadow prices of the optimal solution. Overall, the result is that while such discount factors exist and are not unique, they are of dubious value since they cannot be known until the optimal solution is known (Weingartner, 1977, p. 1427).

Instead of trying to maximize present value under capital hard rationing, a more direct alternative employs the use of undiscounted models. The idea is to let the model implicitly determine the discount rate by maximizing the value of the undiscounted cash flow up to some time period in the future called the "horizon" (Charnes, Cooper and Miller, 1959). Any expected cash flows beyond the horizon are discounted back at some appropriate rate, usually described as either the firm's borrowing or lending rate.

There are a number of different forms of the model (e.g., Bradley, et al., 1978). All of them (1) bypass the need for explicit discounting by allowing cash to accumulate to the horizon, and (2) show that a vector of "consistent" discount prices can be derived from the duals of the optimal solution. The choice of the discount rate for post-horizon cash flows is a problem, but most authors either ignore it completely (Baumol and Quandt) or assume that choosing a sufficiently distant horizon will likely make the optimal solution insensitive to the rate chosen.

In summary, under capital hard rationing, the discount rate cannot be known before the optimal solution is determined, and a present value objective function is not appropriate. The undiscounted model is the appropriate formulation of the capital hard rationing problem.

Soft Rationing

In contrast to hard rationing, soft rationing occurs when the budget ceiling is imposed by management for planning and control purposes; the budget is not viewed as an inflexible constraint. Some form of lending and/or borrowing is allowed. Under such conditions the correct discount rate to use is the cost of capital because the budget constraint is flexible, and the owners and managers are assumed to have access to financial markets for needed funding. Although there has been some confusion on this point, all of Weingartner's models assume soft rationing (Weingartner, 1977). Thus, his present value models may correctly use the firm's cost of capital and his horizon models allow for lending and some constrained borrowing.

Carleton (1969, p. 830) also asserts that present value formulations are feasible when the capital budget is intended to release funds from currently "detailable" projects back to larger "investment pools" of the firm:

> Specified appropriately then, capital rationing is (as Weingartner suggested) an administrative device, and both budgets and discount rate(s) are derived from the long-range financial plan that should rationalize investment decisions. . . . the enumerated projects do not have to constitute an exhaustive description of those to be considered within the firm's planning horizon. Funds not used or released are thus reserved for undetailed uses.

As long as funds can be withdrawn from the model and transferred to the firm's larger investment pool, the appropriate discount factor for each period is related to the marginal return on this larger pool and acts as a surrogate for the firm's unspecified investment activities.

In the context of the PIF program, this latter point seems to apply particularly, as savings generated from each investment project are given first to the organization that generated the idea to offset the valid, unfunded requirements of that organization. Also, rejected PIF projects may later be funded via the Component Sponsored Investment (CSI) program. Therefore, the DoD's PIF program appears to be a case of soft rationing as visualized by Weingartner and Carleton, and the DoD's "social cost of capital" is the appropriate rate to use in a present value MP formulation of the PIF problem.

The Social Cost of Capital

The social cost of capital is the discount rate used in evaluating public investment projects. Determining the rate is no trivial exercise. Prominent economists have debated the social discount rate issue for many years. There are basically two views. Before describing these views, however, reviewing the role and importance of the discount rate is appropriate.

In the late 1960's there was considerable interest in the discount rate because of the emphasis that the Planning, Programming, Budgeting System (PPBS) was receiving in the Federal government. In 1967, the Subcommittee on Economy in Government of the Joint Economic Committee held a series of public hearings on the progress and potential of PPBS. Several prominent economists testified on the role and importance of discounting in public decision making.

The economists testified that the rate was extremely important because of its role in allocating resources between public and private sectors and over time. For example, Baumol (1967, p. 152) described the rate as "a critical datum for the evaluation of any proposed government project." He also testified that choosing a discount rate was tantamount to deciding how to allocate resources between public and private sectors of the economy:

> At stake in the choice of the acceptable discount rate is no less than the allocation of resources between the private and the public sectors of the economy. The discount rate, by indicating what government projects should be undertaken, can determine the proportion of the economy's activity that is operated by governmental agencies, and hence, the proportion that remains in the hands of private enterprise.

Though there appears to be general agreement that the social discount rate is important, there is considerable disagreement regarding what the social discount rate is and how it should be measured. There are basically two views.

The first view is that the rate is an opportunity cost of capital foregone by investment in the public sector. The basic idea is that public investment displaces private investment and should be undertaken only when the public project offers greater benefits than the loss sustained by removing the resources from the private sector. The social discount rate should therefore reflect the returns of displaced private projects. Baumol is perhaps the chief advocate of this position; other advocates of the position include Harberger (1968), Haveman (1969) and Stockfisch (1967).

The second view is that the rate should reflect society's collective time preference. Advocates of this view (e.g., Marglin, 1963; Feldstein, 1974) assert that current market rates overstate the optimal social discount rate. For example, it is suggested that future generations are under-represented in the capital markets, and that the state, acting as a guardian of generations yet unborn, should impose a lower rate of time preference for evaluating public projects (Pigou, 1932).

While the basic concept of an opportunity cost of capital seems simple, measuring it is another matter. There have been many attempts. Basically, an assumption has to be made about how the public project is financed, and what portion of public resources is taker from business and what portion is taken from private consumption. Krutilla and Eckstein (1958), for example, tied the rate to taxes by estimating the reduction in private consumption and investment associated with various forms of taxation.

The rate has also been estimated by taking a weighted average of pretax returns in the private sector (Stockfisch, 1967; Coats, 1984). In testimony before the Joint Economic Committee, Stockfisch explained his procedure. First, he calculated pretax returns in selected major sectors (both regulated and nonregulated) of the economy by dividing "earning assets" (inventory, plant, equipment, and accounts receivable) by operating income-before-taxes-and-interest to arrive at an estimated fifteen percent return for the unregulated sectors and a ten percent return for the regulated sectors. Second, he calculated the relative amount of spending on plant and equipment that each sector incurred through a five-year period to arrive at ratios of seven-tenths and three-tenths, respectively. Third, these ratios were multiplied times the fifteen and ten percent returns for a weighted average return of thirteen and one-half percent. After adjusting for inflation at an assumed annual rate of three and one-half percent, Stockfisch thus estimated the social cost of capital to be ten percent.

Exactly how a market-independent rate can be determined is uncertain, but there have been some suggestions. Marglin

(1963), for example, has suggested that the rate can be tied to an optimal growth rate for the economy. Somers (1971) has suggested that the rate can be determined from preferences expressed through the ballot box.

The two views on the appropriate social discount rate create a dilemma when the return on a public project lies between the time preference rate and the opportunity cost rate. On one side, optimality requires undertaking additional public investment if the project's rate exceeds the time preference rate; on the other side, shifting resources from private to public sectors is inefficient when the return on displaced private investment is greater than the return on public investment.

However indeterminate the optimal rate may be, Baumol (1968) favors using the higher opportunity cost rate. After reviewing the arguments against a market-determined social discount rate, Baumol observes that an increase in investment, aside from its allocative consequences, also redistributes income from present to future generations. Assuming that the next generation will likely be wealthier than the present generation, "a redistribution to provide more to the future may be described as a Robin Hood activity stood on its head--it takes from the poor to give to the rich" (p. 800).

Estimates of the social discount rate are listed in table 5. Most of the estimates were based on data from the 1960s, when Congressional interest was at its peak. As a result of the Office of Management and Budget (OMB) circular and DoD instruction, most government agencies now use the ten percent rate for the social cost of capital. Table 5 has been adapted and updated from Shishko, 1976, p. 10. The column designated "Year" refers to the year to which the estimate applies. Shishko adjusted for inflation by calculating a geometric average of inflation rates in the six years prior to the year of estimate. Coats' estimate was added to table 5 by this author.

TABLE 5

ESTIMATES OF THE SOCIAL DISCOUNT RATE

Author(s)	Year	Nominal Rate	Real Rate
Krutilla and Eckstein	1958	6.0	4.6
Hirshleifer, DeHaven, Milliman	1960	10.0	8.4
Bain, Caves, and Margolis	1966	6.0	4.7
Haveman	1966	7.3	6.0
DoD Instruction 7041.3	1966	--	10.0
Stockfisch	1965	12.0	10.7
Harberger	1968	10.7	8.3
Baumol	1968	10.0	7.7
OMB Circular A-94	1972	--	10.0
Seagraves	1969	--	13.0
Dorfman	1975	--	7.5
Coats	1980	--	8.5

Given the variety of measurement approaches and competing ideas regarding the social discount rate, it is easy to understand the assessment of Prest and Turvey (1965, p. 735):

> The truth of the matter is that, whatever one does, one is trying to unscramble an omelette, and no one has yet invented a uniquely superior way of doing this.

Although the exact value of the social discount rate is uncertain, it does appear to be bounded. According to Baumol, most economists would agree that the time preference rate is less than the oppportunity cost rate. A weighted average of market rates thus constitutes a reasonable upper bound on the social discount rate. In addition, Baumol (1967, p. 159) asserts that the time preference rate has a lower bound: "No serious economist would argue for a social discount rate below the current long-term yield on government bonds."

The fact that the rate is bounded suggests the utility of sensitivity analysis. For example, the optimal economic mix could be found using the DoD's ten percent real discount rate. The sensitivity of the mix to changes in the rate could then be explored. If the mix does not change, the decision maker has increased confidence that the mix is optimal; if the mix changes, the decision maker can at least make a more informed decision. Furthermore, it is possible that the mix identified by IP can be shown to be superior to mixes identified by ranking across wide ranges of discount rates. Thus, while the social discount rate may never be determined, it is possible to demonstrate that mixes identified by IP are economically superior to mixes identified by ranking via sensitivity analysis.

Sensitivity Analysis

Post-optimality analysis procedures (including sensitivity analysis) are well-established in LP. Unfortunately, the optimal integer solution is often extremely sensitive to changes in the coefficients and resource values because the mix is not a function of continuous variables. Also, many IP algorithms add new variables and constraints to more efficiently arrive at a solution. This effectively changes the problem and complicates the interpretation of the shadow prices (Geoffrion and Nauss, 1977). In short, the potential for erratic and unpredictable changes in an optimal IP solution is a serious limitation of the IP formulation to the capital rationing problem.

There are several approaches to the problem of sensitivity analysis in IP. One approach is to re-solve the problem using alternative values. But re-solving the problem over ranges of coefficients and resource values has obvious efficiency difficulties. Another approach is to allow the decision variables to take on continuous values between zero and one. Thus, the zero-one constraint is replaced by $X(i) <= 1$, LP is used instead of zero-one programming, and any fractional solution included in the optimal mix is rounded. (This is essentially the approach recommended by Weingartner). In the case of hard rationing, fractional projects can either be rounded down or investigated to see if smaller (re-scaled) versions of the same project are possible. In the case of soft rationing, fractional projects can be rounded up or down because the ceiling is flexible. Re-scaling may also be possible.

In the PIF program, re-scaling is not presently considered an option. However, it seems likely that if an organization is faced with the option of either re-scaling or not receiving any funding, re-scaling would receive serious attention. Alternatively, the DoD may offer to partially fund the fractional projects, with the remainder of the costs funded from some other source. Weingartner (1963, pp. 35-36) has shown that the number of fractional projects will not exceed the number of constraints expressing the budget ceilings and project relationships (e.g., mutually exclusive projects). In the PIF program, this means that the number of fractional projects identified by LP would probably be no more than one to three projects from an average of seventy projects selected.

The LP approach coupled with rounding certainly seems promising. There are, of course, no guarantees that (1) the rounded solution is the optimal integer solution, (2) the budget is sufficiently soft to accomodate the fractional projects, or (3) the fractional projects can be scaled-down. Even with these caveats, however, the MP approach will always result in mixes at least as good as any mix identified by ranking.

The Multiple Objective Limitation

Another potentially serious limitation of the traditional MP formulation of the capital rationing problem is the single-criterion objective function. Survey research reveals that most firms have multiple objectives, use multiple criteria, and do not employ MP in their capital rationing decisions (e.g., Klammer, 1972, Banda and Nolan, 1972; Osteryoung, 1973; Gitman and Forrester, 1977; Farragher, 1986). It is not known if the existence of multiple criteria discourages these firms from using MP models.

Given multiple criteria, the attractiveness of a ranking strategy like the one used in the PIF program is understandable. Ranking is an easy way to incorporate multiple objectives. Also, some firms may use more than one selection criterion as an ad hoc adjustment for uncertainty. For example, the most popular primary selection criterion is internal rate of return (IRR); the most popular secondary selection criterion is payback. Some authors (e.g., Clark, et al., 1979; Weingartner, 1969) suggest that while payback is recognized as a naive economic criterion, it is retained as a filter for increasingly uncertain cash flow estimates in the outyears.

As an alternative to the ranking strategy, multiple objective programming can be used. Goal programming (GP) has probably been the most successful approach to multiple objective programming (Kornbluth, 1973; Lin, 1980; Hannan, 1984). While both GP and ranking are satisficing approaches to the capital rationing problem, GP offers at least one advantage over ranking--control. In GP the decision maker can pre-specify desired levels of achievement for each objective or goal; in ranking, the decision maker does not have this ability. The solution mix determined by ranking may have a large return on investment (ROI), but this cannot be pre-specified.

A GP formulation of the capital rationing problem is presented below, where P(k) is the "preemptive priority" assigned to goal k (k=0 is reserved for system constraints), such that P(k) >>> P(k+1); dn(j) and dp(j) are the negative and positive deviations of the jth goal constraint; A(j,i) is the coefficient (e.g., cost, labor savings, NPV) of the ith project associated with the jth goal constraint; g(j) is the desired level of the jth goal; and all other variables are as specified in Weingartner's formulation presented earlier:

$$\text{Minimize} \quad Z = \sum_{k=0}^{K} \sum_{j=1}^{J} P(k)*[dn(j) + dp(j)] \tag{10}$$

Subject to

$$\sum_{i=1}^{N} A(j,i)X(i) + dn(j) - dp(j) = g(j), \quad \text{for } j = 1, \ldots, J \tag{11}$$

$$dn(j),\ dp(j) >= 0 \qquad \text{for } j = 1, \ldots, J \tag{12}$$

$$\sum_{i=1}^{N} C(t,i)X(i) <= B(t) \quad \text{for } t = 1, \ldots, T \quad (13)$$

$$X(i) = \{0,1\} \quad \text{for } i = 1, \ldots, N \quad (14)$$

The GP objective function (equation 10) typically minimizes the deviations from the desired levels of the various objectives or goals. These deviations also appear in the goal constraints (equation 11). Goal constraints describe the desired levels of the various goals. Both the goals and their relative priorities must necessarily be pre-specified by the decision maker. (When there are two or more commensurate goals assigned to the same priority level, numerical weights for the deviation variables may also be included in the model. If used, these weights must also be pre-specified). Equation 12 requires the values of the deviation variables to be non-negative. Equations 13 and 14 are system constraints that enforce economic and other requirements, and are the same as those appearing in Weingartner's formulation.

The linear GP model, introduced by Charnes and Cooper (1961) and later extended by Ijiri (1965), Lee (1972), Ignizio (1976) and others, can handle large-scale problems with thousands of decision variables (Ignizio, 1981). The reported computational efficiency of integer GP models, however, has not been very encouraging. In experiments testing branch-and-bound, cutting plane and implicit enumeration IP algorithms, Lee and Morris (1977, p. 288) conclude that "if the problem had more than twenty variables, it was difficult to obtain the optimal solution within a reasonable time limit." Also, in a recent survey of multiple-criteria zero-one programming models, Rasmussen (1986, p. 93) concludes that while considerable progress has been made in the last seven years, multiple-criteria zero-one models are "in general only applicable to smaller problems."

While direct (noninteractive) approaches to multiple-criteria zero-one programming presently appear to be infeasible for large-scale problems, it may be possible to employ an indirect (interactive) approach. One indirect approach involves solving the multiple-criteria zero-one problem sequentially with a single-criterion zero-one LP model (Ignizio and Perlis, 1979; Masud and Hwang, 1981). First, the solution for the highest priority goal is found with only system constraints limiting the feasible region. The solution to this problem is then added as a system constraint and the next highest priority goal is placed in the objective function. In this manner, each lower-priority goal will have a successively smaller feasible region because any portion of the region previously eliminated cannot be reexamined. The computational efficiency of such a procedure would therefore be as good as the single-criterion zero-one software employed.

A limitation of direct and indirect approaches is the need for prioritized goals. First, GP requires target values for each goal. Simply maximizing or minimizing a high-priority criterion will fix the solution mix for all lower priority goals. In the PIF program, this requires that the DoD specify goals for IRR, ROI, and manpower reductions. Second, all goals must be prioritized and possibly weighted (if commensurable). It is likely that the solution mix will be sensitive to the priorities assigned, especially for zero-one decision variables (Lee, et al., 1985). In the PIF program, the relative priority of IRR, ROI and manpower reductions is necessary before applying the GP approach. Interactive GP approaches, of course, would provide some information regarding trade-offs among goals by changing the priorities and re-running the model.

A fairly new approach that overcomes the need to pre-specify prioritized goals is called "fuzzy" IP (Zimmerman, 1978; Hannan, 1981). Fuzzy programming is also an interactive approach. First, the aspiration level of each objective is determined by maximizing each criterion subject to the same set of system constraints. This determines the highest possible value for each objective considered separately. Next, the lowest admissible value for each objective is determined from the mixes which yield the aspiration levels for the remaining objectives. The difference (tolerance interval) between the aspiration level and lowest admissible value is then calculated for each objective. A table summarizing this information is prepared for the decision maker to use in establishing goal targets.

Alternatively, the tolerance interval can be used to transform the original model into a fuzzy IP model. The fuzzy IP model can be solved using standard integer software. Headly (1980) has developed fuzzy IP software for application to multiple-objective capital budgeting problems; however, the software is capable of handling problems up to only 150 decision variables.

The Uncertainty Limitation

The MP formulations considered until now have assumed conditions of certainty. In most cases, however, all of the key variables in the capital rationing models (i.e., investment cost, cash flow, economic life and cost of capital) are uncertain. Many approaches have been developed to recognize uncertainty. These range from ad hoc or informal approaches (e.g., imposing payback constraints, increasing the required hurdle rate, shortening the economic life, and requiring conservative estimates) to more formal approaches that attempt to identify the means, variances and probability distributions of the relevant variables, and the decision maker's utility preference for risk. In the absence of historical data, determining the probability distributions of the relevant variables of each project by simulation, (Hertz, 1964; Kryzanowski, Lusztig and Schwab, 1972) or by assumption (Hillier, 1969) has been suggested.

There are several approaches to applying MP models under conditions of uncertainty. Salazar and Sen (1968) have suggested a stochastic LP approach that combines simulation and LP. Using Monte Carlo simulation, random cash flow data for each project are generated and the optimal objective function value is determined by LP. When all simulation runs have been performed, the objective function values are plotted on a "risk-return axis" and presented to the decision maker to select a mix consistent with his/her risk preferences.

Another approach is chance-constrained programming (CCP), developed by Charnes and Cooper (1963). In CCP, the expected value of the objective function is maximized subject to chance constraints. Chance constraints are normal constraints that are allowed to be violated by some percentage specified by the decision maker. The approach assumes some or all of the model parameters are stochastic with known means, variances and normal distributions. CCP has been applied to the Weingartner model (Naslund, 1966; Byrne, Charnes, Cooper, and Kortanek, 1967; Hillier, 19 7). However, the usual formulation of CCP results in a linear objective function subject to nonlinear chance constraints, which are extremely difficult to solve in large-scale problems (Waters, 1966; Petersen, 1975).

The final approach is quadratic programming (QP). In applying QP to capital rationing, a nonlinear objective function is optimized subject to linear constraints. As in CCP, the mean, variance and distribution of each project is assumed to be known. The objective function includes the sum of each project's return (e.g., NPV) less the adjusted variance-covariance matrix, reflecting the covariance between project returns. The variance-covariance matrix is adjusted by a coefficient reflecting the decision maker's risk preference. Integer QP models have been developed (Mao and Wallingford, 1968). However, because the variance-covariance matrix grows exponentially with the number of projects, computational efficiency problems are severe.

At present, only informal adjustments for uncertainty are made in the PIF program. At the Office of the Secretary of Defense (OSD), all PIF data are treated as nonstochastic. At DoD organizational levels below the OSD, probability analysis is encouraged, but the results are generally not reported. However, a four-year payback constraint is enforced. Also, the DoD discount rate is already risk-adjusted because it was determined by taking a weighted average of private sector returns, each of which includes a risk premium. In addition, post-audit data on approved PIF projects are presently inadequate to determine probability distributions (Lenio, 1984).

Attempting to apply any formal method that requires project means, variances and known distributions (e.g., integer CCP or QP) is therefore not possible at present. The simulation approach also appears infeasible at present, because (1) cash flow values against which to apply probability ranges are not known, (2) reasonable probability ranges are not known, and (3) the method would be extremely time consuming, requiring numerous IP runs.

The Computational Efficiency Limitation

A limitation of all integer MP models is the computational efficiency of the IP algorithm. The potential impact of this limitation on specific MP approaches has been referenced throughout this chapter. Experiments conducted in the 1960s and 1970s comparing several IP algorithms indicated that computational efficiency was a concern when there were more than one hundred variables (Gue, Liggett and Cain, 1969; Pettway, 1973). Occasionally, however, IP algorithms have been applied successfully to problems with thousands of variables and hundreds of constraints (Woolsey, 1971).

Current trends in large-scale zero-one programming algorithms involve combining artificial intelligence with management science techniques. Results of exact (optimal solutions) and heuristic (near optimal solutions) algorithms are quite promising. Crowder, Johnson and Padberg (1983), for example, found optimal solutions for real world problems ranging from 33 to 2,750 zero-one variables on an International Business Machines (IBM) 370 mainframe computer. The largest problem required less than one hour of central processing unit (CPU) time. Major building blocks for the algorithm were IBM's Mathematical Programming System Extended (MPSX/370) and IBM's Mixed Integer Programming/370 (MIP/370). Recently, Glover and McMillan (1986) report a new algorithm that integrates management science and artificial intelligence techniques capable of solving problems with four million zero-one variables to within ninety-eight percent optimality. The algorithm is particularly attractive because the test problems were run on an IBM personal computer with only 128 kilobytes of memory, and the solution times were less than thirty minutes. In addition, certain heuristic algorithms are reported to be able to handle large-scale integer GP problems (Ignizio, 1976, 1980, 1985; Petersen, 1974).

Generally, it appears that the solution time is (1) more dependent on the number of variables than on the number of constraints, and (2) extremely unpredictable (Schrage, 1984, p. 186). Small IP problems may take more time to solve than large IP problems. Changes in the model coefficients and right-hand-side values can drastically change the solution time. In short, perhaps the only way to know if established IP algorithms can be applied to the PIF problem is to try them.

Conclusion

This chapter described the general MP approach to the capital rationing problem. The approach can overcome many of the limitations of ranking, including (1) the lumpiness effect, (2) project indivisibilities and inter-relationships, and (3) multiple-budgets. The MP approach also affords the decision maker capabilities not possible with ranking. For example, management can pre-specify desired levels of achievement for any number of objectives in capital rationing by using GP. However, the MP approach has some potentially serious limitations, including the discount rate, the existence of multiple criteria, uncertainty and computational efficiency (table 6). Each of these limitations was described in detail by reviewing the academic literature treating the topic.

Ways to overcome each limitation were also described. With regard to the discount rate, the appropriate MP formulation depends on the type of rationing involved. A careful analysis of the rationing problem in context will suggest either a present value or horizon value formulation. In addition to the proper specification of the MP model, the optimality of the solution mix can be explored by sensitivity analysis, such as (1) relaxing the integer constraint and using LP parametrics, and (2) comparing the mix found by IP against the mix found by ranking through a wide range of discount rates. Also, various MP formulations can incorporate multiple objectives and uncertainty. Finally, recent advances in IP algorithms and computer technology seem quite promising: the size of the capital rationing problem may no longer be a serious impediment to the successful application of MP.

TABLE 6

SUMMARY OF MP LIMITATIONS IN CAPITAL RATIONING

Limitation	Possible Approaches
Discount rate	Analyze type of rationing
Hard rationing	Use a horizon model
Soft rationing	Use a present value model
Uncertainty	Sensitivity analysis
	Stochastic programming
	Chance-constrained programming
	Quadratic programming
Multiple objectives	Goal programming
	Direct (automatic)
	Sequential (interactive)
	Fuzzy programming
Computational efficiency	Recent zero-one software
	Heuristic software
	LP software and consider
	Rounding
	Re-scaling
	Partial funding

This chapter has necessarily dealt in generalities. Despite MP's limitations, applying MP to the capital rationing problem is both desirable and feasible. In the next chapter, the focus narrows to a description and rationalization of methodology for applying MP to the PIF program. Specific procedures regarding hypothesis testing, sensitivity analysis, and MP parameter specification are explained.

CHAPTER 4

METHODOLOGY

The purpose of this study is to investigate the appropriateness and feasibility of applying mathematical programming (MP) to the Department of Defense (DoD) Productivity Investment Fund (PIF) capital rationing problem. In chapter 2, it was established that (1) an optimizing approach is consistent with the economic objective of the PIF program and (2) if MP can be applied, material dollar savings are likely. The DoD currently uses ranking to select projects for funding. Ranking is not an optimizing approach and has limitations that can be overcome if MP is used. Therefore, the hypothesis for this study is: the mix of PIF projects identified by MP is economically superior to the mix identified by ranking.

In chapter 3, the feasibility of applying MP to any large-scale, multiple-criteria capital rationing problem was described; the limitations of MP and ways of dealing with them were reviewed. Generally, a suitable MP model requires a careful consideration of the specific capital rationing problem.

This chapter is divided into three sections. First, the research design is described using a series of flowcharts.

Second, procedures for dealing with the MP limitations are described and defended in the context of the PIF program. Third, details regarding the parameters for the MP models, hypothesis testing, sensitivity analysis, the DoD database, and the tools used to explore the feasibility question are explained.

Research Design

A series of flowcharts (figures 1 through 7) describe the research design. As illustrated by figure 1, the research design is divided into three phases. In the first phase (already accomplished), the software and database were developed and verified. In the second phase, the mixes are selected by integer programming (IP) and ranking. In the third phase, the mixes selected by IP and ranking are compared.

Figures 2 and 3 illustrate the first phase. Figure 2 illustrates the steps involved to develop and verify the software. The four required software packages are listed. Each package was tested using simple test-data and problems to verify that the software functioned properly. Figure 3 illustrates the steps required to develop and verify the database. From printouts provided by the Defense Productivity Program Office (DPPO) on the Fiscal Year 1985 (FY85) PIF program, each project's annual costs and savings were entered into a personal computer (PC) to form the PC database. The PC database was tested by comparing total

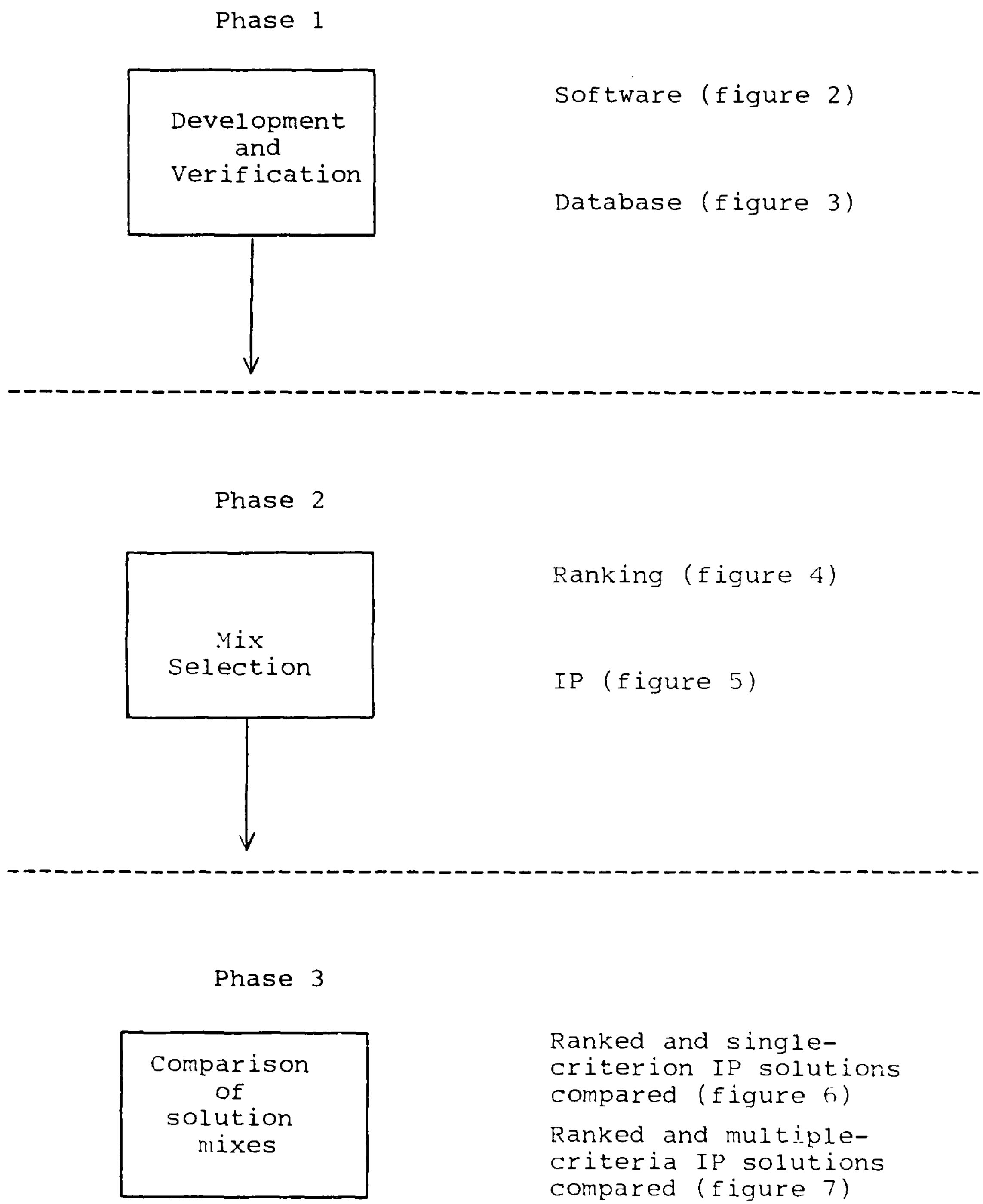


Figure 1 Overview of methodology

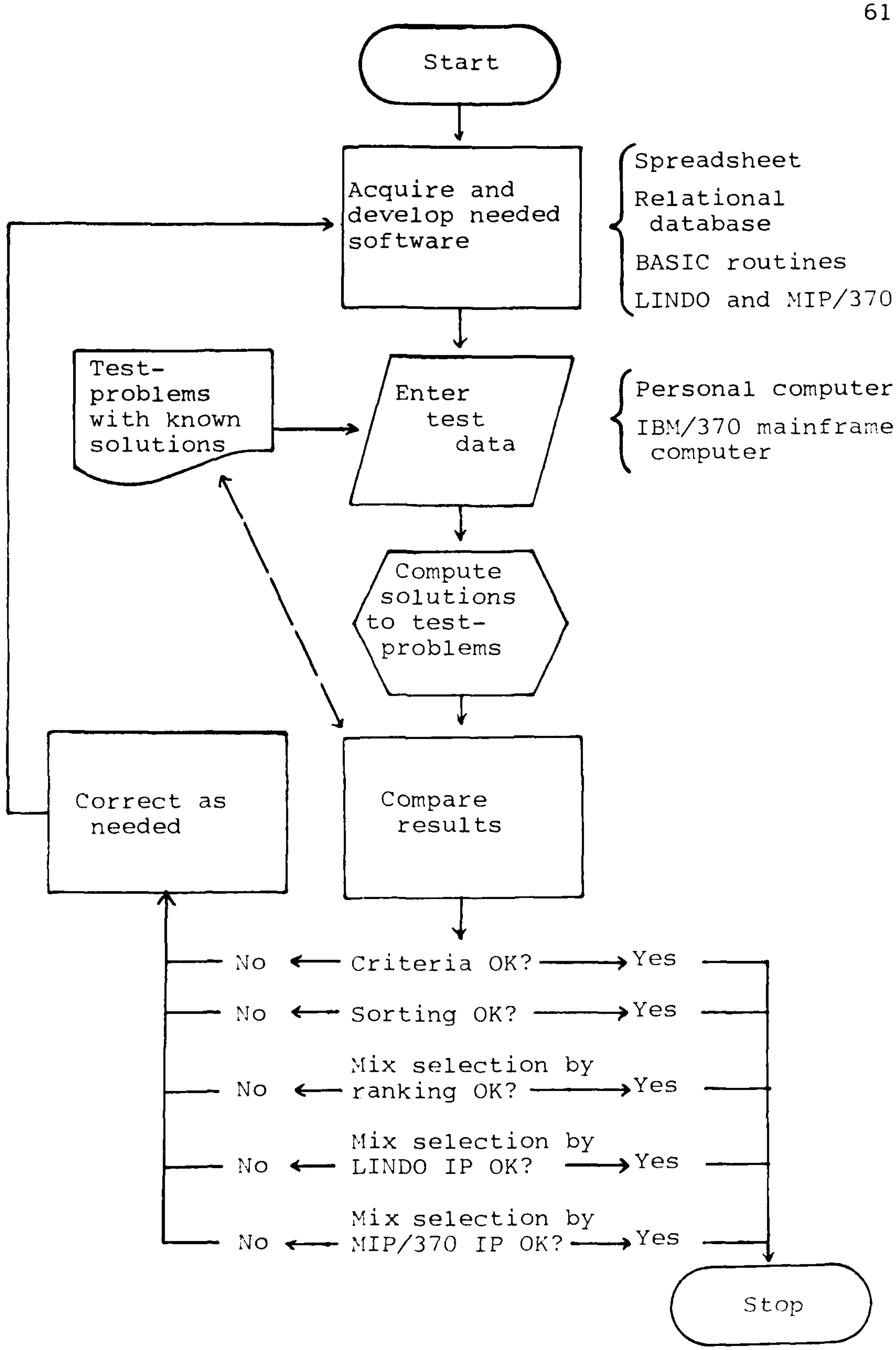


Figure 2 Software development and verification

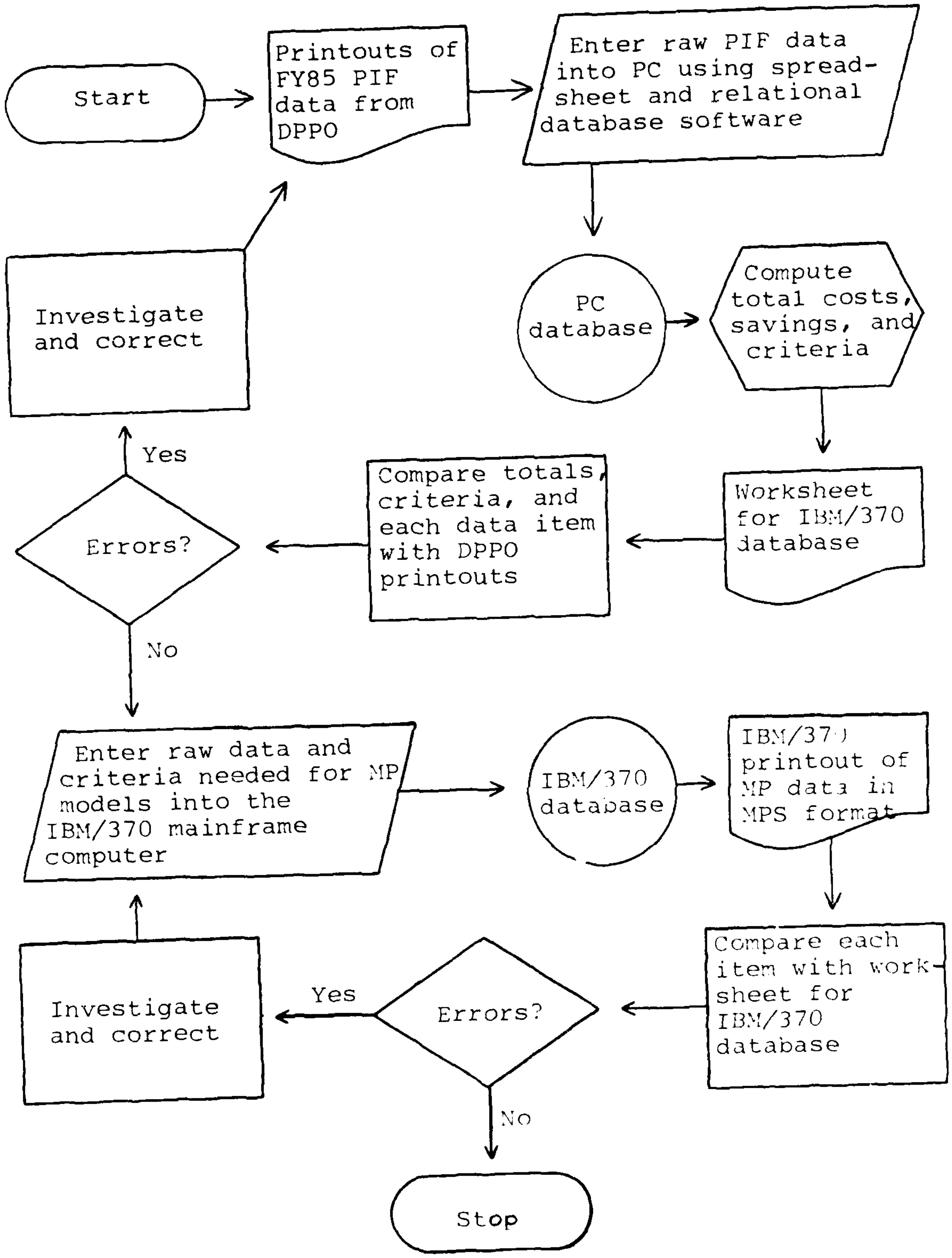


Figure 3 Database development and verification

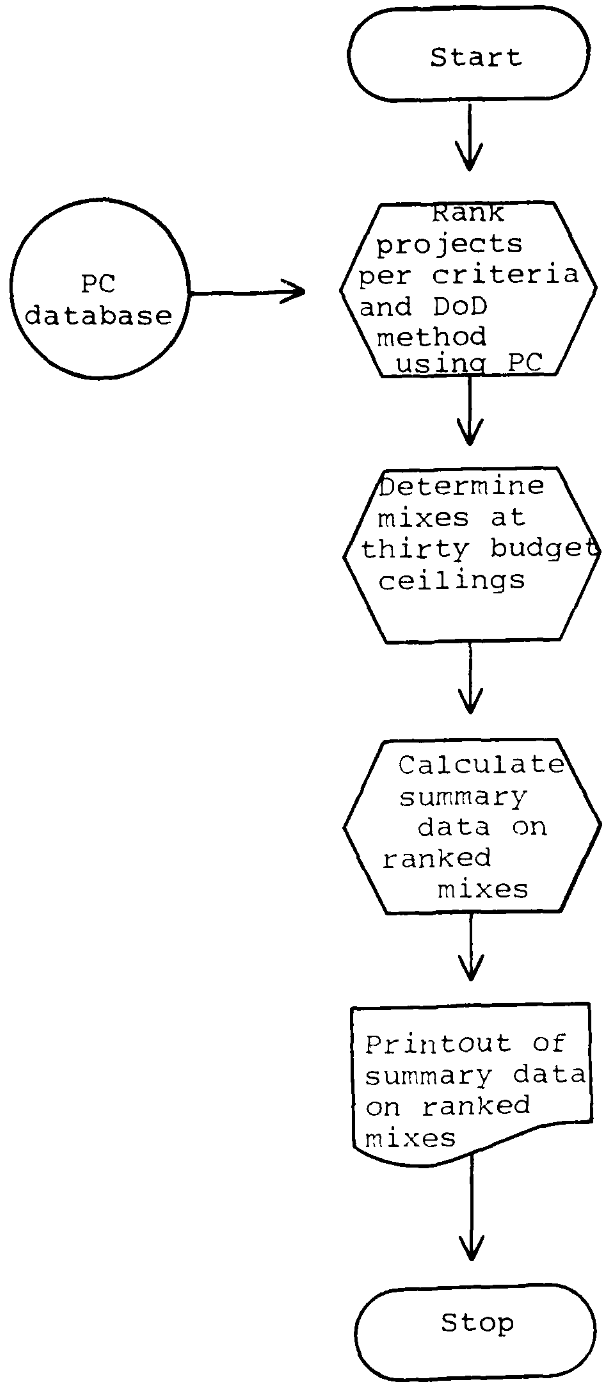


Figure 4 Mix selection by ranking

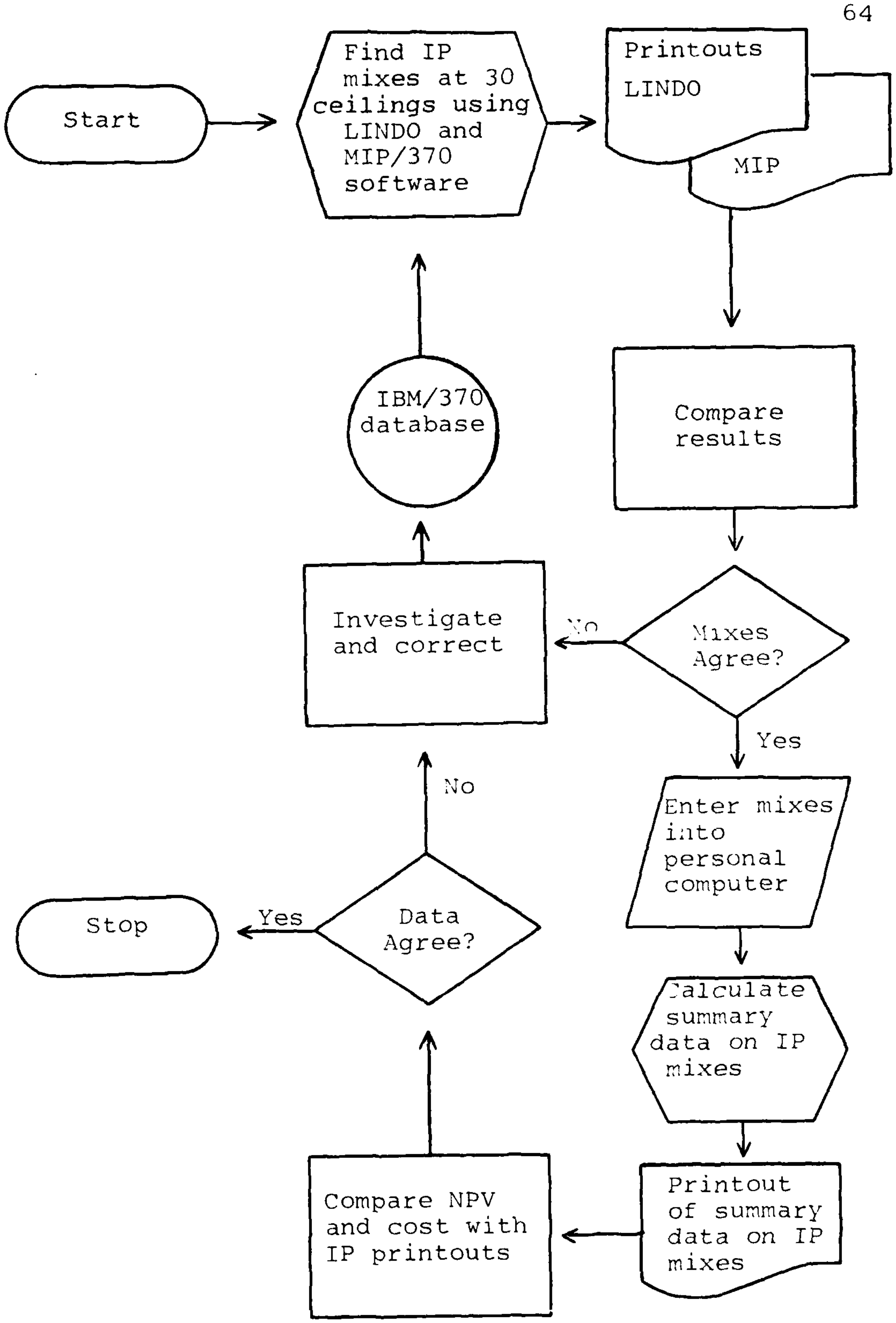


Figure 5 Mix selection by IP

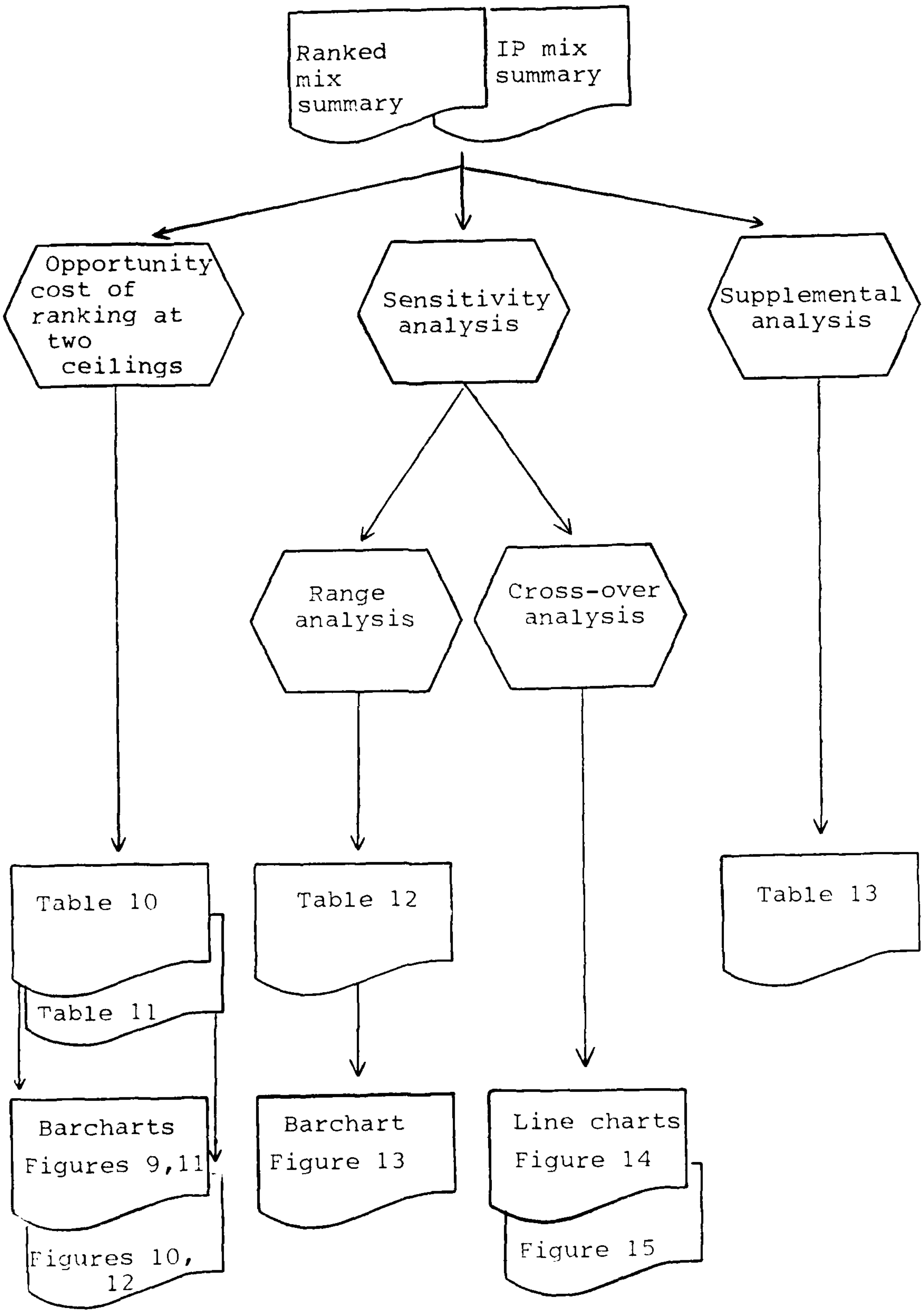


Figure 6 Ranked and single-criterion solution mixes compared

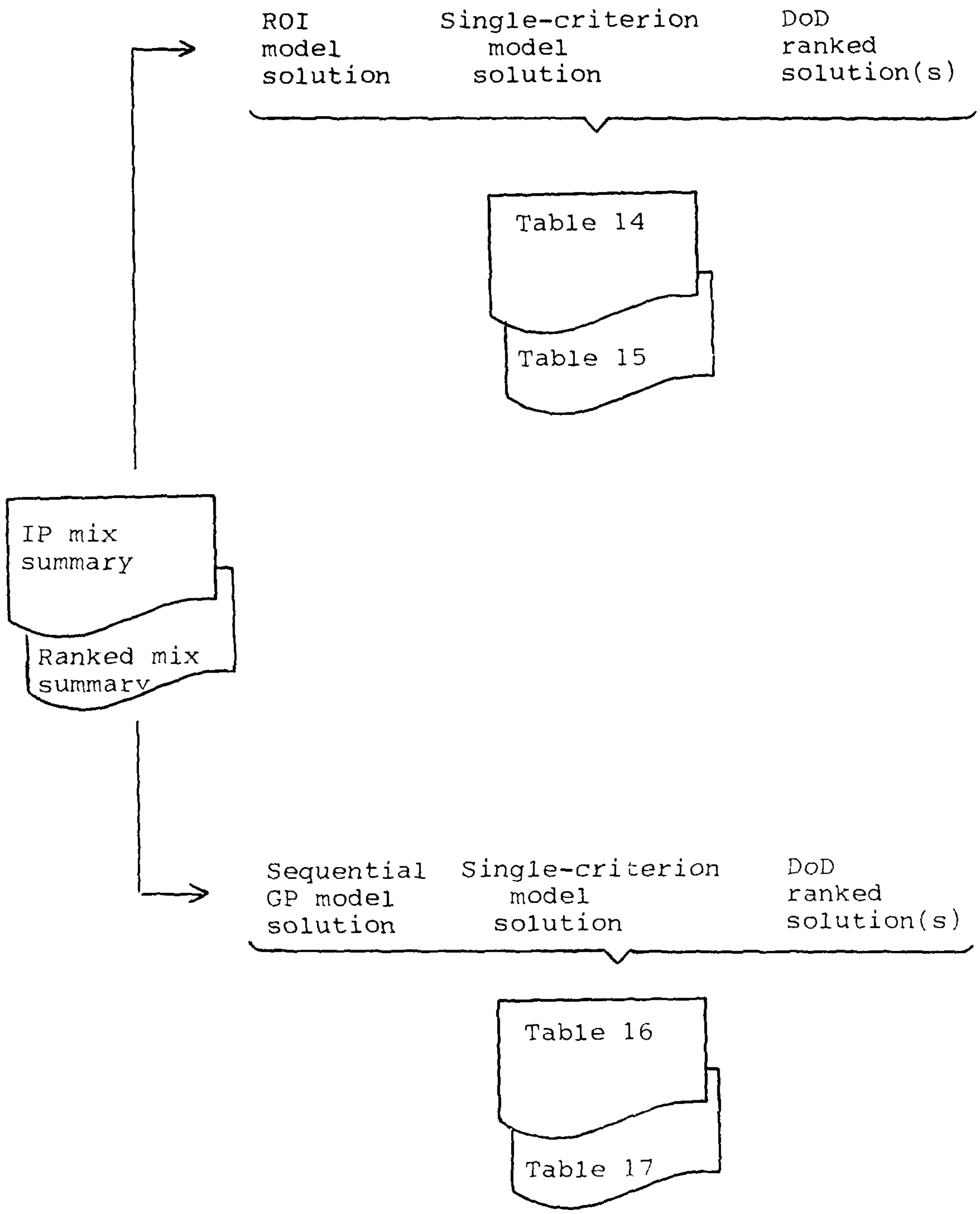


Figure 7 Ranked and multiple-criteria solutions compared

costs, savings, and criteria calculated by the PC with the summary data listed on the DPPO printouts. In addition, an item-by-item comparison between the DPPO printouts and the worksheet from the PC database was accomplished to assure that all the numbers agreed. All errors were investigated and corrected. Once the validity of the PC database was established, the worksheet from the PC database was used to enter data into an IBM/370 mainframe computer. A similar item-by-item comparison was accomplished to insure that the PC and IBM/370 databases agreed.

The second phase of the study concerns mix selection by ranking (figure 4) and IP (figure 5). In figure 4, the projects are first sorted according to each criterion and the DoD method by using the PC software and database. In all, six ranked listings are developed and stored within the PC. Next, mixes are selected from each listing at each of the thirty budget ceilings. Summary data on each mix are calculated and listed on a printout. In figure 5, each IP software package (LINDO and MIP) is used to calculate mixes at the thirty budget ceilings. If the identified mixes agree between packages, the mixes are next entered into the PC database where summary data are calculated. The summary data from the PC are compared to the summary data from the LINDO and MIP printouts to verify that the PC database contains the correct IP mixes at each budget ceiling. All discovered discrepancies are investigated and corrected.

The third phase of the study is described in figures 6 and 7. These figures illustrate the various routines used to compare the ranked and IP solution mixes. For each routine, tables and/or charts are used to summarize the results.

Procedures for Dealing with MP Limitations In the Context of the PIF Program

The Discount Rate Limitation in Context

For the PIF capital rationing problem, Weingartner's present value model is the appropriate formulation, with net present value (NPV) as the single-criterion maximand calculated at the DoD's cost of capital. As explained in chapter 3 (pp. 32-37), the appropriate MP formulation of the capital rationing problem depends upon the type of rationing involved. The PIF program is essentially a case of soft rationing (Carleton, 1969) because (1) savings generated from approved PIF projects may be used by the DoD organizations that initiated the PIF projects to finance valid, unfunded requirements, and (2) projects not selected may later be funded from alternative DoD programs, such as the Component Sponsored Investment (CSI) program. Horizon models (e.g., Baumol and Quandt, 1965), are not appropriate because these models assume hard rationing, in which savings are reinvested internally until the investment horizon is reached. In the PIF program, savings may be withdrawn before the investment horizon is reached and reinvested in projects not explicitly part of the PIF program. The implicit investment pool is therefore much larger than the group of approved PIF projects; an appopriate discount rate related to this larger investment pool is the DoD's cost of capital.

A NPV maximand is chosen for a number of reasons. First, other actual or potential criteria are inferior and/or inconsistent with the economic objective of the PIF program. The DoD has chosen to use three criteria for project selection: internal rate of return (IRR); return on investment (ROI); and a labor savings criterion, investment cost per manpower space saved (CPM). As described in chapter 2 (pp. 20-24), when these criteria are used either collectively or separately in a ranking-based approach to project selection, the identified mix is almost certainly not optimal. Both ROI and CPM are not optimal in an economic sense because they do not adjust for the time value of money. Similarly, NPV is preferred to IRR on theoretical grounds: the implicit reinvestment assumption of IRR does not fit the PIF program and there may be more than one IRR for a given project (a multiple root problem).

Second, economic ratios, including the three DoD criteria and various forms of benefit-cost ratios, are not directly additive; thus, ratios are not naturally and easily employed as a maximand in a linear MP formulation of capital rationing problem. Of the criteria considered, only NPV is directly additive.

Third, NPV is consistent with the objective of the PIF program and is already specified by DoD regulation as appropriate. Using a criterion already specified by DoD regulation should ease implementation difficulties common in management science approaches (Wysocki, 1979).

Fourth, a NPV criterion facilitates hypothesis testing. The total NPV of the mix identified by IP should be equal to or greater than the total NPV of the mix identified by ranking (equation 15); any difference between the two mixes constitutes a dollar savings (opportunity cost) to the DoD (equation 16):

$$\text{NPV(IP mix)} \geq \text{NPV(ranked mix)} \tag{15}$$

$$\text{Opportunity Cost} = \text{NPV(IP mix)} - \text{NPV(ranked mix)} \tag{16}$$

The NPV maximand consists of the NPV of each PIF project calculated at the DoD's cost of capital, now set at ten percent (DoD Instruction 7041.3, 1972; Office of Management and Budget Circular No. A-94, 1972). The DoD regulations are rather unclear regarding the origin of the prescribed rate, but based on the Congressional hearings in 1967 and 1968 (chapter 3, pp. 38-40), the rate appears to reflect the opportunity cost of capital viewpoint, and agrees exactly with the calculation of Stockfisch (1967). Since this rate is (1) currently mandated by DoD regulation, and (2) verifiable from market rates in the private sector, it is preferable over the subjective time-preference rate. In any case, because the social discount rate is bounded, sensitivity analysis can be easily applied.

The Multiple Criteria Limitation in Context

As already stated, the use of multiple selection criteria virtually guarantees that the optimal economic mix is not identified in the PIF program. It is recognized, however, that an exact approach to project selection may not be acceptable given the influence of special interests. A satisficing approach may be more descriptive of the PIF program. Accordingly, a demonstration of two multiple-criteria MP approaches using PIF data is provided to highlight what can be done when multiple, often conflicting objectives constrain rationality. The demonstration is not intended to be exhaustive, just illustrative. The NPV of the multiple-criteria solution will be less than or equal to the NPV of the exact solution. Any difference constitutes the economic opportunity cost of the multiple-criteria approach.

In the first demonstration, the single-criterion NPV maximand is retained, but additional system constraints may be enforced for any number of objectives or criteria. A right-hand-side value for each criterion employed as a constraint must necessarily be assumed. Also, because the additional constraints are hard (system) constraints, they have an implicit priority over the NPV maximand.

In the second demonstration, sequential goal programming (GP) is used, where the underachievement of several criteria is minimized. The GP approach is sequential because no suitable automatic integer GP software is readily available. Thus, the underachievement of each goal is sequentially minimized, beginning with the highest priority goal. The priorities and levels for each goal must necessarily be assumed.

The Uncertainty Limitation in Context

For several reasons, all formal adjustments for uncertainty are essentially ignored when calculating the solution mixes using the various MP models. First, the PIF payback restriction is an informal adjustment for uncertainty (e.g., Blatt, 1979). Second, the DoD discount rate is a weighted average of returns in the private sector (chapter 3, p. 40). Since these private sector returns are not risk-free, a weighted average of them is also not risk-free. Third, post-audit data on approved PIF projects are not available (Lenio, 1984; General Management Systems, 1986), making the objective determination of project means, variances and distributions impossible. Fourth, subjective approaches are possible but not practical, given the limited access to the DoD personnel who developed the estimates for each project. Finally, sensitivity analysis usefully explores the potential impact of uncertainty, and is a method recommended by the DoD for dealing with the problem of uncertainty (DoD Instruction 7041.3, 1972, pp. 13-14). In this study, varying the discount rate and budget ceiling through wide ranges of values is used to explore the generalizability of the hypothesis.

The Computational Efficiency Limitation in Context

Two commercial software packages capable of handling large-scale zero-one capital rationing problems are readily available for use on an IBM 370 mainframe computer. The first software package, called "LINDO" (an acronym for Linear Interactive Discrete Optimizer), is available in several versions, depending on the computer system. On mainframes, LINDO is capable of handling linear, zero-one, and quadratic MP formulations of up to 800 rows and 4,000 columns (Schrage, 1984). The second software package, IBM's Mixed Integer Programming/370 (MIP/370), is an optional feature of IBM's Mathematical Programming System Extended/370 (MPSX/370). The MIP/370 program logic provides for a maximum of 16,383 rows and 32,727 integer variables. However, as the IBM _Primer_ (p. 57, 1979b) states:

> . . . a realistic limit for the number of integer variables is _very much smaller_ and is dependent on the problem type and structure.

Both LINDO and MIP/370 use the branch-and-bound method to compute successive integer solutions. In this method, the values in each solution become the lower bound of subsequent solutions. The upper bound is usually the value of the relaxed linear solution. The solution time for particular problems are difficult to predict, but for problems similar in size to the PIF problem, a solution time of less than one minute would not be uncommon (IBM, 1979c).

While the use of two software packages is not necessary, comparing solutions from the two packages is a useful control technique. If neither zero-one package proves adequate, relaxing the integer constraint and using linear programming (LP) is a reasonable alternative. As explained in chapter 3, the fractional projects identified in LP solutions of the PIF problem may reasonably be investigated for rounding, re-scaling or partial funding. Also, because GP is a satisficing approach, a linear GP solution may be just as viable as an integer GP solution.

Specific Procedures and Methodological Details

Hypothesis Testing

The hypothesis testing applies only to the single-criterion, NPV model. The other MP models are demonstrations of alternative satisficing approaches to project selection. Their primary advantage over the ranking approach is control: the decision maker can enforce (through specified constraints) the achievement of any number of feasible objectives on the solution mix. In the ranking approach, the decision maker cannot similarly shape the characteristics of the solution.

The hypothesis is not amenable to statistical significance tests. Using equations 15 and 16 (p. 70), the NPV of the solution found by IP is compared to the NPVs of the mixes found by ranking based on (1) the DoD selection criteria used together, (2) the DoD selection criteria used separately, and (3) two alternative criteria currently not used by the DoD, NPV and excess profitability index (EPI). In all, six mixes found by ranking are compared to the mix found by IP.

Two budget ceilings are used to test the hypothesis: \$136.4 million and \$73.1 million. The first budget ceiling is the total amount allocated to the FY85 budget before reductions for previously approved PIF projects. The effective ceiling in the FY85 PIF program is not apparent from the PIF data provided by the DPPO. All continuing investment costs of previously approved PIF projects reduce the funds available for current PIF projects. The effective FY85 budget for competing PIF projects is thus less than \$136.4 million. Since data on these projects were not provided, their exact impact on the effective ceiling can only be estimated. A reasonable estimate of the effective ceiling is the actual cost of the mix funded that year, \$73.1 million. The actual ceiling was probably slightly higher than \$73.1 million, as it is extremely unlikely that the funded mix would exactly exhaust the budget ceiling. Using the actual cost of the funded mix introduces a conservative bias on the results. The opportunity cost of ranking will be slightly higher than the amount calculated using equation 16.

In addition to the two budget ceilings described above, twenty-eight other ceilings ranging from \$10 to \$280 million (in \$10 million increments) are used to explore the generalizability of the results. Overall, as the budget level increases, the difference between the solution mixes should narrow because the budget is less binding on the solution. At $280 million, the budget is no longer binding; every project can be funded. The twenty-eight budget values will not reveal the number and exact levels where integer changes in the solution mix occur (changes in the basis). As explained in chapter 3 (p. 44), a linear parametric analysis of the budget is not feasible with binary decision variables.

The Multiple Criteria Demonstration

The ROI Model

There are two multiple-criteria MP demonstrations. In the first demonstration, NPV is maximized subject to the budget ceiling and an additional constraint reflecting a desired objective or goal of management. Almost any criterion can be used. For this study, ROI is selected because it is a reasonable measure of productivity--a stated objective of the PIF program. The other DoD criteria are not as desirable: the CPM criterion has less generalizability (only the DoD uses it); the IRR criterion is not linear (its use in a linear IP model is not appropriate). A reasonable right-hand-side value for the ROI constraint is the largest ROI achieved by any of the ranking methods. In this way, the mix identified by the ROI model will have a ROI that is at least as large as any found by ranking, but with a larger (potentially) NPV.

For convenience, a NPV maximand is retained in the first demonstration. NPV is directly additive; ratios are not. There are technical difficulties with using ratios in the objective function of MP models. Awerbuch, Ecker and Wallace (1976) note that in fractional GP problems, multiplying through by the denominator and solving the associated linear GP problem is not a proper transformation. A number of authors have suggested methods for handling fractional criteria (e.g., Charnes and Cooper, 1962; Joksch, 1964; Bitran and Novaes, 1973; Soyster and Lev, 1978; Hannan, 1981; Kornbluth and Steuer, 1981; Kornbluth, 1984). In general, problems with ratios arise only if they are used in the objective function. It is the minimizing or maximizing of deviations from goal constraints involving ratios that causes difficulties. When ratios are used as hard constraints, multiplying through by the denominator is proper (Spronk, 1981, pp. 206-208). Therefore, to avoid the technical difficulties associated with fractional GP, NPV is maximized subject to ROI and budget constraints.

The Sequential GP Model

The second multiple-criteria demonstration involves sequential GP. Here, the underachievement of three goals is sequentially minimized. The first two goals involve labor savings realized from each PIF project. There are two types of labor savings: authorized and equivalent. Authorized labor savings (La) are whole manpower spaces that can be eliminated if the investment project is approved. Equivalent labor savings (Le) are calculated when a particular investment project will not eliminate a whole manpower space, but will reduce labor hours. In this case, the total number of hours saved by a project in one year is divided by the standard number of hours estimated for a typical manpower space in one year. For example, suppose a project will save 11,648 labor hours each year. Assuming eight hours per day, five days per week, and fifty-two weeks per year, there are 2,080 labor hours in a year. Thus, there are 5.6 (11,648 divided by 2,080) equivalent manpower spaces saved from this hypothetical project. The DoD prefers whole manpower savings to equivalent manpower savings (chapter 2, p. 17). Reasonable preemptive priorities for the two labor goals are: La, first; Le, second. The third priority goal in the sequential GP model is NPV. After the underachievement of the labor goals is minimized, the underachievement of NPV is minimized.

In addition to specifying the goal priorities, values for each goal must also be assumed. In this demonstration, the largest labor savings achieved by any of the six ranking methods, "Maximum (ranked)," is used for both labor goals. For example, if the maximum value of La achieved by any ranking method is 560, then 560 is the target for the La goal. Similarly, if the maximum value of Le achieved by any ranking method is 1,860.7, then 1,860.7 is the target for the Le goal. For the NPV goal, the maximum level achieved by

IP is used. Since this level will be the highest possible NPV for an integer solution mix, NPV is being maximized subject to the prior achievement of the other two goals.

Other goals, priorities and target values are possible. For example, President Reagan has set a goal of twenty percent productivity improvement in the Federal government by 1992 (Executive Order 12552, 25 February 1986). This goal could easily be expressed by setting appropriate values for ROI, labor savings, EPI, *et cetera*. However, since the multiple-criteria MP models are intended only as demonstrations, additional formulations are not necessary. Table 7 summarizes the sequential GP model:

TABLE 7

SUMMARY OF THE SEQUENTIAL GOAL PROGRAMMING MODEL

Goal	Priority	Target value	Objective
La	1	Maximum (ranked)	Minimize underachievement
Le	2	Maximum (ranked)	Minimize underachievement
NPV	3	Maximum (IP)	Minimize underachievement

Sensitivity Analysis

The mix found by the single-criterion IP model is compared with the mix found by the DoD method in two ways. First, in range analysis, the discount rate is held constant while the budget ceiling is varied over a wide range of values. Second, in cross-over analysis, the budget ceiling is held constant while the discount rate is varied over a wide range of values. The intent of both analyses is to establish the economic superiority of the IP mix over the DoD mix through wide ranges of discount rates and budget levels.

A sensitivity analysis of the multiple-criteria MP models is also possible. For example, the priorities of the goals could be changed and the models re-run. Different budget levels and goal targets could also be assumed. However, these models are only demonstrations; accordingly, no sensitivity analysis will be conducted involving them.

Range Analysis

Multiple budget ceilings are intended to demonstrate the generalizability of the hypothesis; i.e., the opportunity cost of ranking will be nonnegative at every budget level examined. In total, the mixes found by the IP and DoD ranking methods are compared at thirty budget levels, ranging from $10 to $280 million. Rationale for these levels has already been provided (pp. 75-76).

Cross-over Analysis

A cross-over analysis (Fisher, 1930) is conducted by comparing the NPVs of the IP and DoD mixes through a wide range of discount rates. The cash flow of a typical PIF project is negative in the early years of the project's economic life, reflecting a large initial investment cost, and positive in the remaining years, reflecting the annual savings. The NPV of any cash flow with this characteristic pattern will decrease as the discount rate increases (Bussey, 1978, p. 207).

Figure 8 illustrates the discounted cash flows of two hypothetical mixes compared over a range of discount rates. The NPV of the mix labeled "IP" is greater than the NPV of mix labeled "DoD" when the discount rate is between zero and 7.2 percent. The NPV of the IP mix is greater than the NPV of the DoD mix at discount rates greater than 7.2 percent. The NPVs of both mixes are zero at their respective IRRs. When the discount rate is greater than the IRR of a mix, the NPV of that mix is negative.

The discount rate that equates the NPVs of the two mixes, termed the "cross-over rate" in the study, is used in a sensitivity analysis comparing the IP and DoD mixes. The following steps are employed at the two budget ceilings identified for detailed analysis ($73.1 million and $136.4 million). First, the mixes determined by the IP and DoD methods are identified. Second, the net cash flow of the DoD mix is subtracted from the net cash flow of the IP mix, yielding a differential cash flow. Third, the IRR of the differential cash flow is calculated to determine the cross-over rate. If there is only one cross-over rate (one IRR) for the differential cash flow, the NPV of the mix determined by IP will be larger than the NPV of the mix determined by ranking from discount rates ranging from zero to the cross-over rate. At discount rates greater than the cross-over rate, some other mix is probably superior to the

	Cash flow (millions)			Rate	Selected NPVs (millions)		
Yr	IP mix	DoD mix	Difference	(%)	IP mix	DoD mix	Difference
0	-100.0	-100.0	0.0	0.0	40.0	30.0	10.0
1	10.0	50.0	-40.0	5.0	20.7	18.0	2.7
2	30.0	40.0	-10.0	7.2	13.3	13.3	0.0
3	40.0	30.0	10.0	10.0	4.9	7.9	-3.0
4	60.0	10.0	50.0	15.0	-8.0	-0.8	-7.2

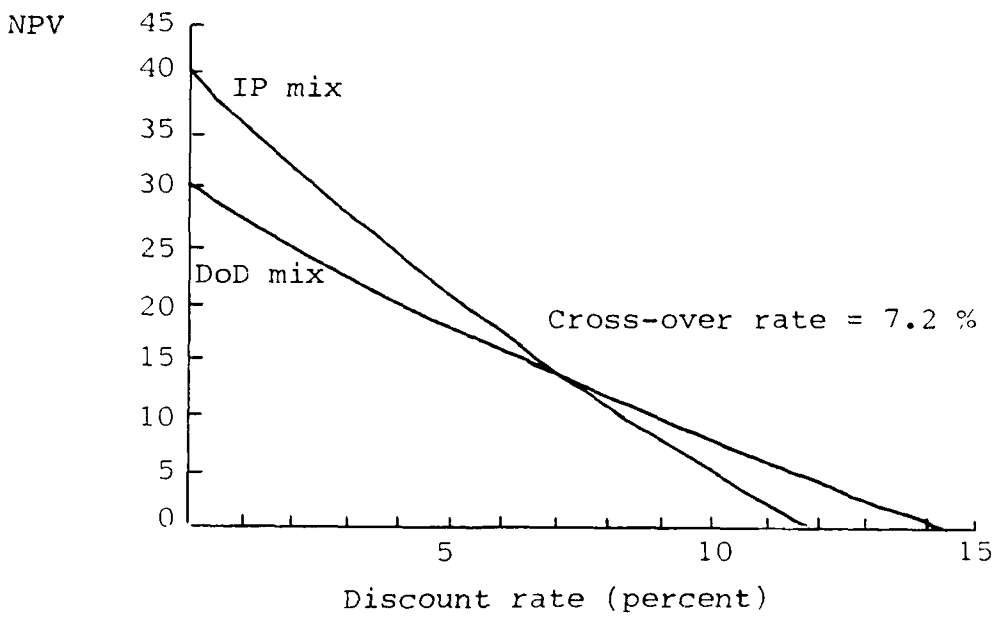


Figure 8 Cross-over analysis

DoD mix. However, if the cross-over rate is large, say greater than any reasonable return seen in the private sector, then concern about the appropriate value for the discount rate is unfounded because the economic superiority of the IP mix over the DoD mix is established at all reasonable discount rates.

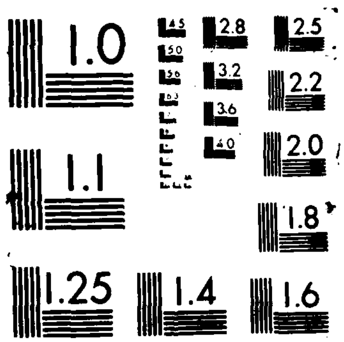
Supplemental Analysis

Two additional calculations involving the LP solution provide additional insight into the PIF capital rationing problem. In a LP formulation of the PIF problem, the zero-one constraint is relaxed to allow the decision variables to assume fractional values between zero and one. The LP formulation is useful for (1) identifying the opportunity cost [illegible] enforcing the integer constraint on all PIF projects, and (2) identifying the marginal benefit of finding the optimal integer solution.

In IP algorithms, LP is used to establish upper and lower bounds on the optimal value of the integer [illegible] In the single-criterion formulation, the NPV of the [illegible] tion will be greater than or equal to the NPV of the [illegible] solution. If the LP solution mix has no fractional [illegible] it is also the optimal integer solution. If the [illegible] fractional projects, a lower bound on the optimal [illegible] solution is established by excluding all [illegible] from the LP mix. IP algorithms use these [illegible] the number of combinations requiring [illegible]

AD-A186 153 THE APPLICATION OF MATHEMATICAL PROGRAMMING TO THE PRODUCTIVITY INVESTMEN..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH D S CHRISTENSEN 1987 2/3

UNCLASSIFIED AFIT/CI/NR-87-133D F/G 12/4 NL


1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

In addition to facilitating the computational efficiency of IP algorithms, these bounds provide useful information. First, the difference in the NPVs of the LP and IP solutions is the maximum opportunity cost of enforcing the integer constraint on all projects in the PIF program. Currently, a project is either completely accepted or completely rejected; fractional projects and partial funding are not options. If they were, additional savings may be realized by funding the fractional projects. Second, determining the IP mix may be very time consuming. The difference between the LP and rounded LP solutions is the maximum marginal benefit (rounding error) of pursuing an optimal integer solution. A small rounding error indicates that the rounded LP solution is near optimal; insisting on an optimal solution that appears to involve considerable computer time may not be cost effective.

The PIF Database

The DPPO maintains a computerized database on PIF projects submitted since Fiscal Year 1982. For this study, the DPPO has provided data on all FY85 PIF projects. Summary statistics on the FY85 PIF project data are listed in table 8. Estimated annual dollar savings, annual labor savings (authorized and equivalent) and annual investment costs for each of the 186 projects are provided in the Appendix (table 18). Criteria calculated from the raw data on each project, including IRR, ROI, NPV, CPM and EPI, also appear in table

18. The DPPO assigns an eleven-position alphanumeric code to each project. This code provides detailed information regarding the source and nature of the project. However, to preserve anonymity, the projects listed in table 18 are identified by a number which represents the DoD ranking order (1 to 186).

TABLE 8

SUMMARY STATISTICS ON FY85 PIF PROJECT DATA

	Minimum	Maximum	Average	Total
Investment Costs (millions)				
Project Year 0	0.104	15.530	1.455	270.598
Project Year 1	0.0	3.651	0.084	15.673
Project Year 2	0.0	5.109	0.065	12.154
Project Year 3	0.0	0.100	0.0	0.100
Total	0.104	15.530	1.605	298.525
Savings				
Dollar (millions)	0.3	537.3	21.3	3965.3
Labor (manpower positions)				
Authorized	0.0	120.0	3.0	560.0
Equivalent	0.0	650.0	21.4	3989.6
Total	0.0	650.0	24.4	4549.6
Economic indicators				
IRR (percent)	11.7	630.0	n/a	90.7
ROI (Savings/Costs)	1.4	77.0	n/a	13.3
CPM (Costs/Labor)	1.1	9999	n/a	65.6
NPV ($ millions)	.01	163.9	8.5	1582.9
EPI (NPV/Costs)+1	1.0	34.8	n/a	6.4

The raw data provided by the DPPO are assumed to be accurate and reasonable estimates of each project. As explained in chapter 2 (pp. 14-16), the DoD screening and review process is exhaustive, involving a review of each project for reasonableness and accuracy at several organizational levels. Also, a private contractor has recently reviewed the entire PIF database and declared it to be "essentially accurate and valid" (General Management Systems, 1986, p. 28).

The DPPO has also provided data on the three selection criteria calculated for each project. In a review of these values it was discovered that IRR is not calculated correctly. The problem involves timing the annual savings differently than the investment costs for discounting purposes. Annual savings are assumed to begin one year after the project becomes operational. However, the annual savings are not discounted consistent with this assumption. Instead, the savings are discounted as if they begin two years (in project year two) after the initial investment costs. The investment costs, assumed to begin in project year zero, are being discounted properly. Thus, the annual discounted savings are systematically understated relative to the discounted costs. When IRR and NPV are calculated using this erroneous procedure, they are also systematically understated. To highlight the error, equations 17 and 18 represent, respectively, the incorrect and correct formulas for calculating IRR, where C(t) is the investment cost in year t; S(t) is the savings in year t; and "r" is the discount rate (IRR) that satisfies the equations.

$$\sum_{t=0}^{T} C(t)/(1+r)*EXP(t) = \sum_{t=0}^{T} S(t)/(1+r)*EXP(t+1) \qquad (17)$$

$$\sum_{t=0}^{T} C(t)/(1+r)*EXP(t) = \sum_{t=0}^{T} S(t)/(1+r)*EXP(t) \qquad (18)$$

Lenio (1984) noted this problem and recommended that it be corrected. The DPPO intends to correct the problem eventually. Since the error applies systematically to all projects, the DPPO assumes (erroneously) that the relative order of the ranked listing is unaffected.

For this study, all the criteria (including IRR) are calculated correctly, using the raw data from table 18. Comparisons between the NPV of the optimal mix found by IP and the mixes found by ranking are based on the correctly calculated criteria.

Tools Used in the Study

The software for the MP models has already been described. Standard personal computer spreadsheet and database software are used to store and manipulate the FY85 PIF data. Both LINDO and MIP/370 are compatible with the *Mathematical Programming System (MPS) format for specifying* MP formulations (Schrage, 1984). This feature greatly facilitates using the two MP software packages in tandem and guarantees that the same data are processed for the same MP problem.

With respect to hardware requirements, both MIP/370 and LINDO are run on an IBM/370 mainframe computer using the Conversational Monitoring System (CMS). The minimum virtual machine configuration to support MIP/370 is 800 kilobytes of storage and mini-disk space equivalent to eight cylinders of a 3330 disk (IBM, 1986). The exact machine requirement for LINDO depends on the system, but an advertisement brochure provided by The Scientific Press (1986) claims that LINDO can run on virtually any mainframe or minicomputer, with a FORTRAN compiler.

Summary

Table 9 summarizes the three MP models of the PIF capital rationing problem described in this chapter. In the first model, IP and LP are used to maximize NPV subject to the PIF budget constraint. The NPV of the optimal integer mix is compared to the NPV of the mixes determined by ranking. The generalizability of the results are investigated by sensitivity analysis, where the budget ceiling and the discount rate are varied through wide ranges. The second and third models are demonstrations of multiple-criteria IP formulations of the PIF capital rationing problem. For these models, the term "Max(ranked)" refers to the maximum value of ROI, La, and Le achieved by any of the selection methods that uses ranking (p. 79); "Max(IP)" is the maximum NPV achieved by IP at the specified budget ceiling (p. 78). The parameters for all the models, the database, and the software and hardware requirements were also explained in detail in this chapter. The results of the tests and demonstrations are described in chapter 5.

TABLE 9

SUMMARY OF THE THREE MP MODELS

	Sing- -criterion IP model	Multi-criteria IP models: ROI	Multi-criteria IP models: Sequential GP
Objective function	Maximize NPV	Maximize NPV	Minimize underachievement
Constraints:			
Budget	yes	yes	yes
ROI	no	yes	no
La	no	no	yes
Le	no	no	yes
NPV	no	no	yes
Right-hand-side values:			
\$73.1 million	yes	yes	yes
\$136.4 million	yes	yes	yes
\$10 to 28 million	yes	no	no
ROI	n/a	Max(ranked)	n/a
La	n/a	n/a	Max(ranked)
Le	n/a	n/a	Max(ranked)
NPV	n/a	n/a	Max(IP)

CHAPTER 5

RESULTS

In chapter 4, several mathematical programming (MP) formulations of the Department of Defense (DoD) Productivity Investment Fund (PIF) capital rationing problem were developed. This chapter describes the results of applying each formulation (model) to 186 PIF projects that competed for funding in Fiscal Year 1985 (FY85).

In the first model, integer programming (IP) is used to maximize the net present value (NPV) of the solution mix subject to a budget constraint. The NPV of the solution mix is compared to the NPVs of mixes found by ranking based on various criteria. The difference between the NPV of the mix found by IP and the NPV of the mixes found by ranking is the opportunity cost of using a heuristic approach (ranking) to project selection rather than using an exact approach (IP). The generalizability of the result is explored by varying the budget ceiling and discount rate through broad ranges of feasible values. Comparisons between the single-criterion IP solution mix and the mixes found by ranking are summarized in tables and figures in this chapter and in the Appendix. Rationale for the single-criterion model and its parameters was provided in chapter 4, pp. 74-76.

The second and third models are multiple-criteria formulations of the PIF capital rationing problem. In the second model, IP is used to maximize the NPV of the solution mix subject to two constraints. The first constraint is for the budget ceiling. The second constraint requires that the selected mix achieve an assumed minimum level of return on investment (ROI). In the third model, sequential goal programming (GP) is used to minimize the underachievement of three goals: authorized labor savings (La); equivalent labor savings (Le); and NPV.

The second and third models demonstrate how multiple criteria may be used in MP formulations to select PIF projects. MP allows the user to search for a mix with any number of desired characteristics. In these demonstrations, the chosen characteristics (expressed as system and goal constraints) are assumed minimum levels for ROI, labor savings, and NPV. Other characteristics are possible (chapter 4, p. 79). The mixes found by the multiple-criteria MP models and by ranking are compared and summarized in tables and figures in this chapter and in the Appendix. Rationale for the multiple-criteria models and their parameters was provided in chapter 4, pp. 76-79.

Results of the Single-criterion Model

In the single-criterion model, NPV is maximized subject to a budget constraint. Two budget ceilings are tested in detail. One ceiling, $73.1 million, is the actual cost of the forty-two PIF projects funded in FY85. This is a conservative estimate of the effective ceiling in FY85 after subtracting the current costs of PIF projects approved in earlier years. The second ceiling, $136.4 million, is the FY85 budget before any adjustments for previously approved projects. The results of the single-criterion model are summarized in tables 10 through 13, and in tables 19 through 22. Tables 10 and 11 are in this chapter; tables 19 through 22 are in the Appendix. Figures 9 through 15, based on the data in the tables, illustrate the results of the single-criterion model.

Conflicting Rankings Confirmed

Tables 19 through 22 list and compare the solution mixes identified by IP and by ranking. The projects are selected by ranking based on (1) the DoD selection method involving three criteria (chapter 2, pp. 17-19), (2) internal rate of return (IRR), (3) ROI, (4) cost per manpower spaced saved (CPM), (5) NPV, and (6) excess profitability index (EPI). The relevant budget ceiling is listed at the top of each table. The data in tables 19 through 22 confirm that conflicting rankings occur when different methods and criteria are used. The mix, the number of projects, and the cash flow for each mix are different for each selection method and criterion used.

Tables 19 and 20 list the solution mixes identified by the IP and ranking methods at the two budget ceilings. To preserve anonymity, the projects are listed in DoD ranking order from 1 to 186. For each mix, a "1" indicates that the project is included in the mix; a "0" indicates that the project is not included. The mix found by IP is listed first; the mixes found by ranking based on the DoD method and the various criteria are listed next. At the bottom of each table, the total number of projects selected by each method (IP, DoD) or criterion (IRR, ROI, CPM, NPV, EPI) is listed. For example, when the budget ceiling is $73.1 million, thirty-five projects are selected using IP; when the ceiling is $136.4 million, seventy-four projects are selected using IP.

The two columns labeled "DoD" are for mixes identified by the DoD method. The column labeled "DoD as if" lists the mix that would have been selected when IRR is calculated correctly (chapter 4, pp. 86-87). The column labeled "DoD actual" lists the mix that was actually funded by the DoD in FY85. Accordingly, this column only applies to mixes determined at the $73.1 million budget ceiling; in tables where mixes are determined at other ceilings, the "DoD actual" column does not appear.

Tables 21 and 22 list the cash flow of each mix selected at the two budget ceilings. The cash flow for a given mix is calculated by totaling the investment costs and savings of the projects included in that mix. The longest economic life of any FY85 PIF project is twenty-six years. Therefore, the estimated annual savings for each mix do not extend beyond twenty-six years. Similarly, no project has investment costs beyond four years. The estimated investment costs for each mix do not extend beyond three years because the projects with investment costs in the fourth year are not included in any mix.

Hypothesis Confirmed

Data in tables 10 and 11 confirm the hypothesis described in chapter 4 (p. 58): the mix of PIF projects identified by MP is economically superior to the mix identified by ranking. The tables summarize the costs and savings achieved for each selection method at the two budget ceilings. Economic indicators, determined from the cash flow of each mix, also appear in the tables. In both tables, the mix determined by IP has the largest NPV. When the budget ceiling is \$73.1 million (table 10), the IP mix has a NPV of \$983.9 million. This is the largest NPV of any mix determined at that ceiling. When the budget ceiling is \$136.4 million (table 11), the result is the same: the IP mix is optimal in the sense that NPV is maximized; the mixes determined by ranking are suboptimal in the sense that NPV is not maximized.

The difference between the NPV of the IP mix and the NPV of a mix selected by the DoD method or criterion is the opportunity cost of ranking based on that method or criterion. The opportunity cost of ranking by IRR, ROI, CPM, NPV, EPI, and the DoD method is nonnegative at both budget

TABLE 10

IP SOLUTION MIX COMPARED TO MIXES DETERMINED BY RANKING

(BUDGET CEILING = $73.1 MILLION)

		DoD Method		Other Ranking Criteria				
	IP	(as if)	(actual)	IRR	ROI	CPM	NPV	EPI
Total in Mix (projects)								
	35	45	42	51	33	55	10	40
Investment Cost (millions)								
YR 0	73.1	73.1	73.1	73.1	73.1	73.1	73.1	73.1
YR 1	10.5	0.9	7.2	3.7	0.6	0.4	3.5	0.7
YR 2	11.6	0.0	7.0	1.9	0.0	0.0	5.1	0.0
Total	95.2	74.0	87.3	78.7	73.7	73.5	81.7	73.8
Dollar Savings (millions)								
Gross	2502	2248	1946	1640	2403	1235	2101	2376
Net	2407	2174	1859	1561	2329	1162	2019	2302
Labor Savings (manpower positions)								
Auth.	180	361	342	340	186	464	17	185
Equi.	2502	2834	2419	2668	2428	3202	2001	2543
Total	2682	3195	2761	3008	2614	3666	2018	2728
Economic Indicators [1]								
IRR	148.8	146.7	134.0	169.3	147.4	129.2	128.9	155.4
ROI	26.3	30.4	22.3	20.8	32.6	16.8	25.7	32.4
CPM	35.5	23.1	31.6	26.2	28.2	20.1	40.5	27.0
EPI	11.7	12.8	10.1	10.7	13.5	8.3	11.3	13.7
NPV	983.9	869.7	778.3	758.4	920.2	533.8	825.3	932.8
Opportunity Cost of Ranking (millions)								
	0.0	114.2	205.6	225.5	63.7	450.1	158.6	51.1

[1] Internal rate of return (IRR) is a percentage. Cost per manpower space saved (CPM), is calculated by dividing total cost (in thousands of dollars) by total labor savings (authorized and equivalent). Net present value (NPV) is in millions of dollars.

TABLE 11

IP SOLUTION MIX COMPARED TO MIXES DETERMINED BY RANKING

(BUDGET CEILING = $136.4 MILLION)

	IP	DoD (as if)	Other Ranking Criteria IRR	ROI	CPM	NPV	EPI
Total in Mix (projects)							
	74	85	76	70	93	24	76
Investment Cost (millions)							
YR 0	136.4	136.3	136.4	136.3	136.3	136.4	136.3
YR 1	15.3	6.0	8.6	4.2	2.3	6.2	8.2
YR 2	11.6	5.1	7.0	5.1	0.0	7.0	7.0
Total	163.3	147.4	152.0	145.6	138.6	149.6	151.5
Dollar Savings (millions)							
Gross	3203	3030	3084	3155	2475	2923	3163
Net	3040	2883	2932	3009	2336	2773	3011
Labor Savings (manpower positions)							
Auth.	440	456	386	272	509	60	440
Equi.	3118	3443	3155	2903	3852	2979	3107
Total	3558	3899	3541	3175	4361	3039	3547
Economic Indicators [1]							
IRR	125.1	128.9	131.7	121.8	106.8	116.8	127.3
ROI	19.6	20.5	20.3	21.7	17.8	19.5	20.9
CPM	45.9	37.8	42.9	45.9	31.8	49.2	42.7
EPI	9.3	9.6	9.7	9.8	8.0	8.9	9.8
NPV	1329.6	1262.9	1301.7	1271.6	964.5	1161.4	1316.4
Opportunity Cost of Ranking (millions)							
	0.0	66.7	27.9	58.0	365.1	168.2	13.2

[1] Internal rate of return (IRR) is a percentage. Cost per manpower space saved (CPM), is calculated by dividing total cost (in thousands of dollars) by total labor savings (authorized and equivalent). Net present value (NPV) is in millions of dollars.

ceilings examined. For example, at a budget ceiling of $73.1 million, the opportunity cost of the projects actually funded by the DoD is $205.6 million. When IRR is calculated correctly (chapter 4, pp. 86-87), the opportunity cost of the DoD selection method is $114.2 million. Similarly, at the $136.4 million ceiling, the opportunity cost of the DoD (as if) mix is $66.7.

Figures 9 through 12 (developed from tables 10 and 11) illustrate that the mix of projects identified by IP is economically superior to the mixes identified by ranking: the NPV of the mix found by IP is greater than the NPV of any mix determined by the ranking-based methods (figures 9 and 10); the difference between the NPV of the IP-based mix and the ranking-based mixes is the opportunity cost of ranking (figures 11 and 12). At the $73.1 million ceiling, the opportunity cost of ranking ranges from $51.1 million to $450.1 million; at the $136.4 million ceiling, the opportunity cost ranges from $13.2 million to $365.2 million.

Sensitivity Analysis

Range Analysis

Table 12 confirms the generalizability of the results. The IP-selected mix is compared to the mixes selected by ranking at twenty-eight budget ceilings. The opportunity cost of ranking is nonnegative at every level tested. The average opportunity cost of ranking, ranging from $23

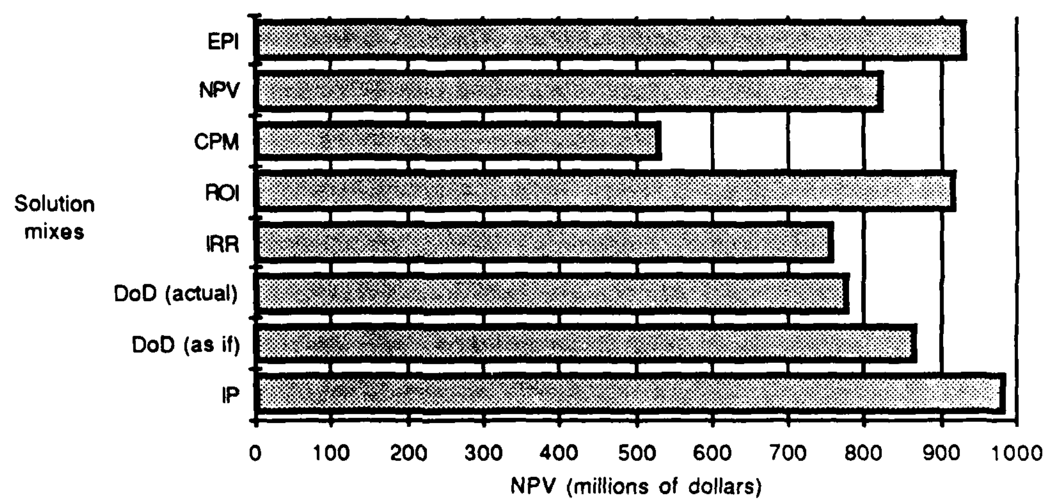


Figure 9 NPV of solution mixes compared
(Budget ceiling = $73.1 million)

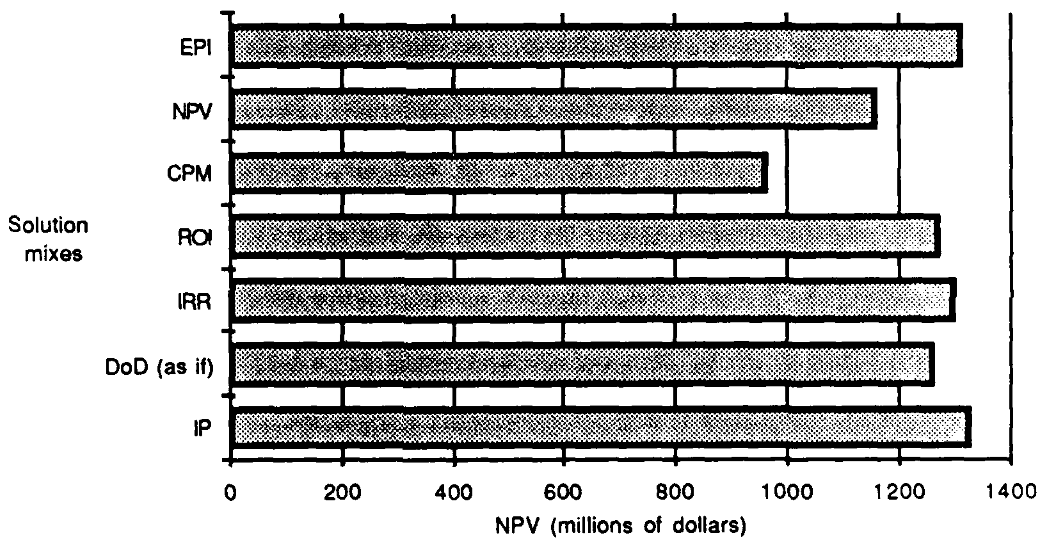


Figure 10 NPV of solution mixes compared
(Budget ceiling = $136.4 million)

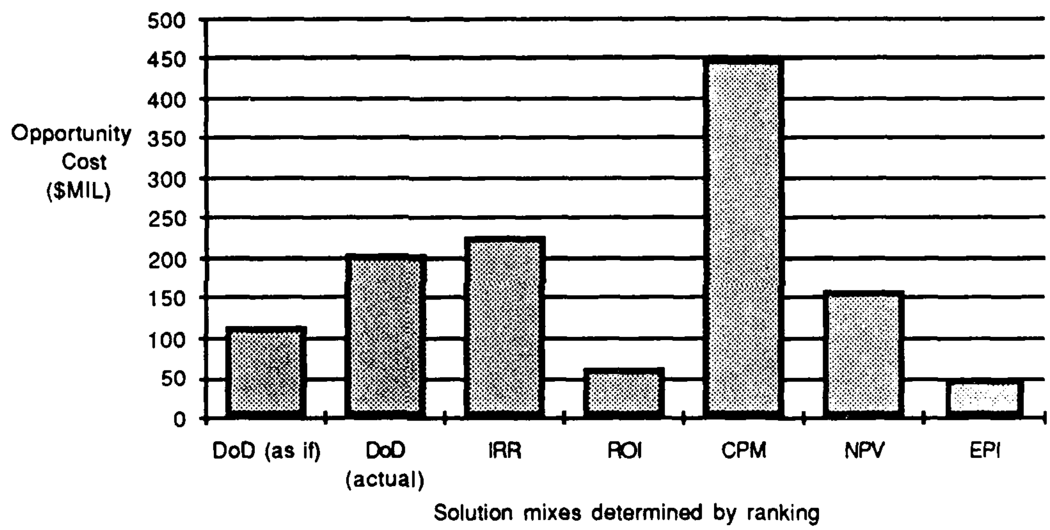


Figure 11 The opportunity cost of ranking
(Budget ceiling = $73.1 million)

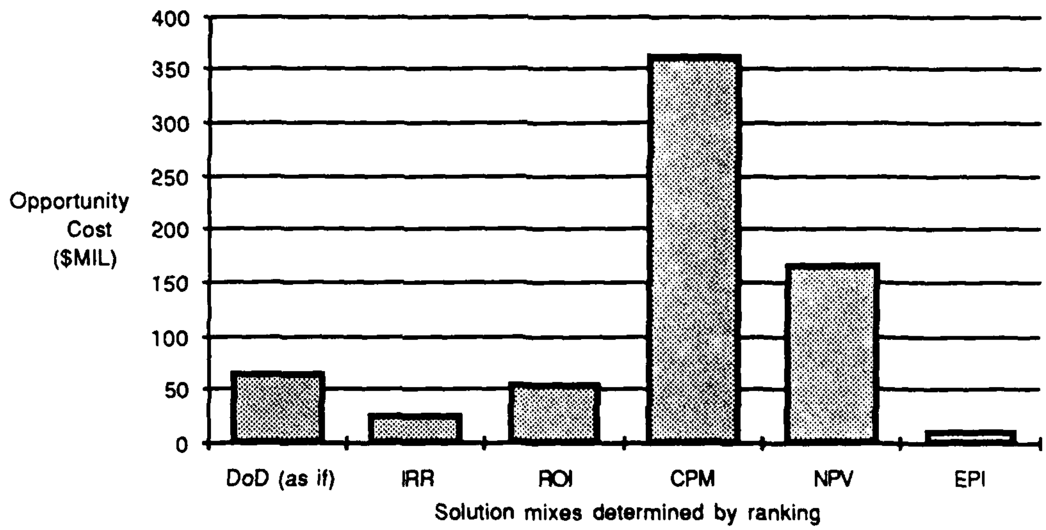


Figure 12 The opportunity cost of ranking
(Budget ceiling = $136.4 million)

TABLE 12 THE OPPORTUNITY COST OF RANKING (RANGE ANALYSIS)

Budget Ceiling ($MIL)	NPV of IP Mix ($MIL)	Opportunity Cost ($ Millions)						Opportunity Cost (Percentage)					
		DoD	IRR	ROI	CPM	NPV	EPI	DoD	IRR	ROI	CPM	NPV	EPI
10	235	73	51	65	96	98	30	31	22	28	41	42	13
20	388	101	88	63	161	170	29	26	23	16	41	44	7
30	523	135	136	53	157	112	37	26	26	10	30	21	7
40	643	184	133	81	222	66	38	29	21	13	35	10	6
50	760	141	141	47	292	159	35	19	19	6	38	21	5
60	862	134	180	44	358	151	39	16	21	5	42	18	5
70	957	105	212	47	429	150	43	11	22	5	45	16	4
80	1028	103	253	66	472	132	54	10	25	6	46	13	5
90	1098	81	245	63	573	228	52	7	22	6	52	21	5
100	1159	115	261	79	555	148	55	10	23	7	48	13	5
110	1215	126	123	72	447	139	63	10	10	6	37	11	5
120	1262	94	79	79	449	137	15	7	6	6	36	11	1
130	1305	68	41	55	460	174	15	5	3	4	35	13	1
140	1342	59	32	56	370	189	14	4	2	4	28	14	1
150	1373	80	45	41	331	123	14	6	3	3	24	9	1
160	1402	50	41	31	340	139	14	4	3	2	24	10	1
170	1432	59	37	49	338	102	14	4	3	3	24	7	1
180	1455	30	25	45	258	88	15	2	2	3	18	6	1
190	1477	26	12	39	222	66	15	2	1	3	15	4	1
200	1499	24	7	36	111	32	15	2	0	2	7	2	1
210	1518	20	6	29	63	43	3	1	0	2	4	3	0
220	1536	22	5	19	44	38	15	1	0	1	3	2	1
230	1551	10	10	18	19	32	3	1	1	1	1	2	0
240	1563	3	2	4	13	23	0	0	0	0	1	1	0
250	1577	7	9	6	8	21	5	0	1	0	1	1	0
260	1578	.3	3	.1	.3	7	.1	0	0	0	0	0	0
270	1583	.7	0	0	.7	0	0	0	0	0	0	0	0
280	1583	0	0	0	0	0	0	0	0	0	0	0	0
Average	1211	66	78	42	242	99	23	5	6	4	20	8	2

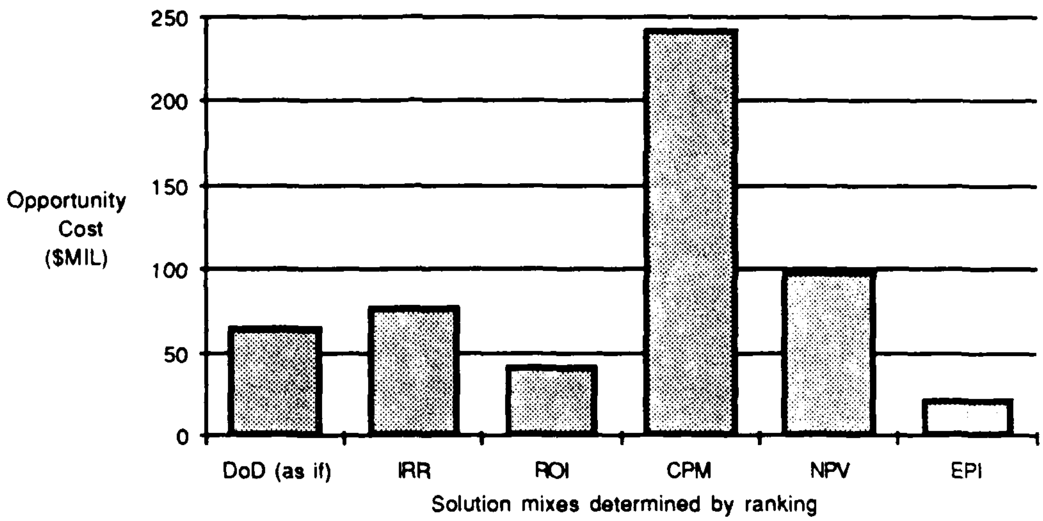


Figure 13 The average opportunity cost of ranking (Range analysis)

million to $242 million, is illustrated in figure 13. As a percentage of the optimal economic mix, the average opportunity cost ranges from two to twenty percent.

Cross-over Analysis

Figures 14 and 15 illustrate the results of the cross-over analysis. The objective is to determine the range of discount rates over which the IP mix is economically superior to the DoD mix. (Details explaining the methodology are provided in chapter 4, p. 80). At the $73.1 million ceiling (figure 14), the NPV of the IP mix is larger than the NPV of the DoD mix at discount rates ranging from zero to 174.7 percent. The point of intersection occurs in the fourth quadrant, where the NPVs of both mixes are negative. At discount rates larger than 174.7 percent, some other mix is probably superior to the DoD mix.

Since the NPVs of both mixes are already negative, extending the analysis beyond the cross-over rate is not necessary: the IP mix dominates the DoD mix (in an economic sense) through all reasonable ranges of discount rates; the economic superiority of the IP mix over the DoD mix is clearly established. At the $136.4 million ceiling (figure 15), the cross-over point also occurs in the fourth quadrant at a discount rate of 1,420 percent. The economic dominance of the IP mix over the DoD mix is apparent.

Discount Rate (%)	NPV (millions of dollars) IP mix	DoD mix	Difference
0	2406.4	2173.7	232.7
20	552.4	484.4	68.0
40	252.1	220.6	31.5
60	138.0	120.9	17.1
80	79.5	69.5	10.0
100	44.5	38.6	6.0
120	21.6	18.2	3.4
140	5.6	3.9	1.7
160	-6.1	-6.7	0.6
180	-15.1	-14.9	-0.2

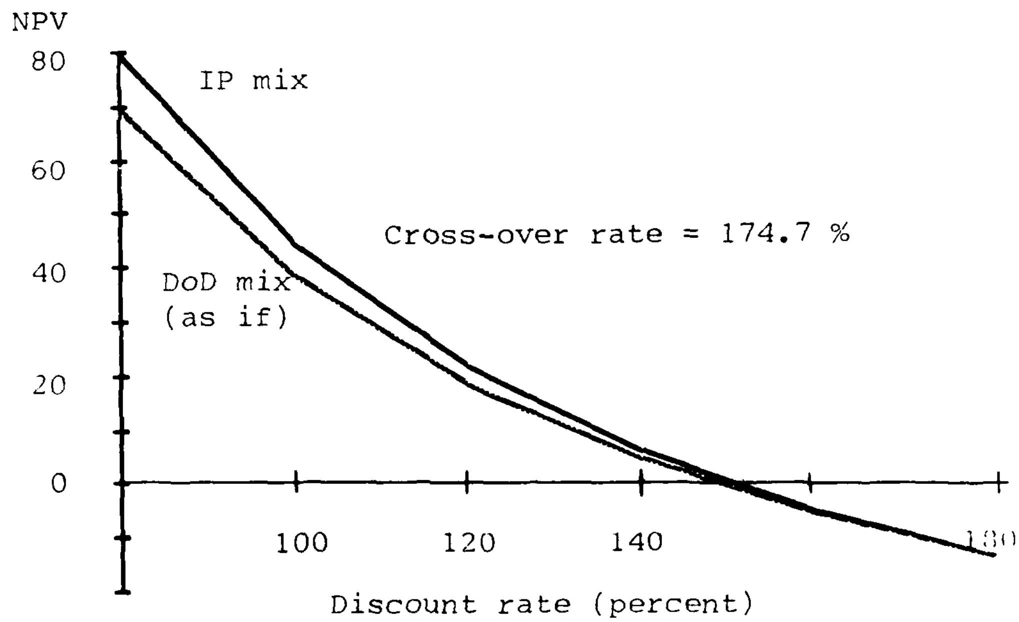


Figure 14 Cross-over analysis
(Budget ceiling = $73.1 million)

Discount Rate (%)	NPV (millions of dollars) IP mix	DoD mix	Difference
0	3059	2883	176
40	358	336	22
80	103	95	8
120	16	11	5
160	-27	-29	2
1000	-121	-122	1
1500	-127	-126	-1

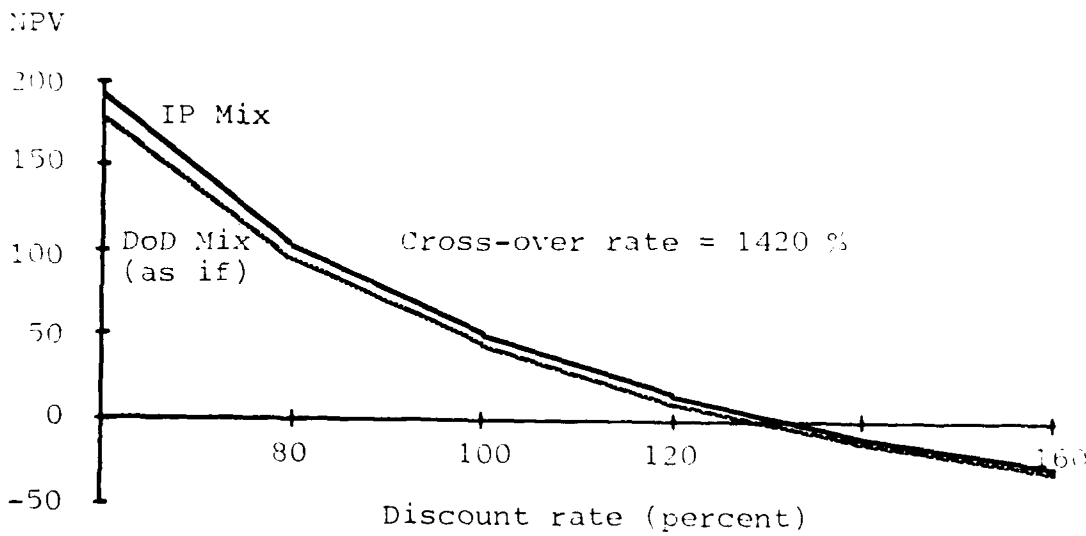


Figure 15 Cross-over analysis
(Budget ceiling = $136.4 million)

Supplemental Analysis

The results of supplemental analysis, involving (1) an examination of the relaxed, linear programming (LP) solution, and (2) the relative effectiveness of the ranking methods, provide additional insight into the PIF capital rationing problem.

The LP Solution Mix

As shown in table 13, the NPV of the IP solution is between the NPVs of the LP and rounded LP solutions. The rounded LP mix is the LP mix with all fractional projects excluded (rounded to zero). If the LP mix is feasible, additional savings can be realized. For example, at the $73.1 million ceiling, additional savings of $0.3 million may be realized if (1) the budget can be adjusted to accomodate the fractional project, or (2) funding the fractional project is reasonable (i.e., the project has constant returns to scale), or (3) partially funding the project can be arranged, where some other source of funds can be combined with PIF money to completely finance the project.

Since there is only one budget constraint in the single-criterion model of the PIF problem, there can only be one fractional project at each of the budget levels tested (chapter 3, p. 45). Hence, at the $73.1 million ceiling, the LP mix includes thirty-five percent of project sixty-one; all other projects are either completely accepted or completely rejected. Similarly, when the budget ceiling is $136.4 million, the LP mix includes ninety-nine percent of project fifty-one; the other projects are either completely accepted or completely rejected. In this latter case, adjusting the budget to accomodate an additional one percent of the cost of project fifty-one appears very promising; i.e., if the $136.4 million budget is increased by $21.0 thousand, additional savings of $200 thousand is realized.

TABLE 13

AN ANALYSIS OF THE LP SOLUTION MIX

(MILLIONS OF DOLLARS)

Budget Ceiling	NPV (rounded LP)	NPV (IP)	NPV (LP)	Opportunity Cost	Rounding Error
73.1	981.7	983.9	984.2	0.3	2.5
136.4	1322.6	1329.6	1329.8	0.2	7.2

The column labeled "Rounding Error" in table 13 is the difference between the LP and rounded LP solutions. If the optimal IP solution mix cannot be found with ease, the maximum loss involved from terminating the search prematurely is represented by the rounding error (IBM, 1979b). In this study, terminating the search prematurely was not necessary; the time required to find the optimal integer solution using the single-criterion model was less than fifteen seconds (of central processing unit time) for every budget level tested.

There is another reason why the LP solution mix should not be ignored. The rounded LP mix may have a larger NPV than the mix determined by ranking. In the two budget ceilings examined, the NPV of the rounded LP solution exceeded the NPV of any mix determined by ranking.

The Relative Effectiveness of Ranking Criteria

A comparison of the mixes determined by ranking provides insight into the relative effectiveness of the various ranking criteria. First, ranking by a single criterion usually results in a mix with the best value for that criterion. For example, the largest IRR achieved among the mixes determined by ranking occurs in the mix that was selected by IRR; the mix with the largest ROI was the one selected by ROI; the mix with the smallest (best) CPM was the one selected by CPM; the mix with the largest EPI was the mix selected by EPI. The only exception occurs when the ranking criterion is NPV. Ranking by NPV does not maximize NPV because the criterion is not measured relative to the resources consumed (the budget ceiling). To assure that NPV is maximized, MP must be used.

Second, in terms of maximizing NPV, EPI was the most effective criterion, and CPM was the least effective criterion. Ranking by the EPI criterion yielded the mix with the largest NPV of the ranking methods compared. This is not surprising because EPI (1) adjusts for the time value of money and (2) measures the contribution of a project per resource consumed. Ranking by the CPM criterion yielded a mix with the smallest NPV. Of the three criteria used in the DoD method, CPM appears to be the least economic; i.e., it is probably most responsible for the large opportunity costs of the DoD mixes. For example, at the $73.1 million ceiling, the opportunity cost of the mix determined by CPM ranking is twice the opportunity cost of the mix determined by IRR ranking and over seven times as great as the opportunity cost of the mix determined by ROI ranking.

Finally, ranking by the DoD method did not result in a superior mix in terms of any single criterion. The use of several selection criteria in capital rationing cannot be expected to optimize any one of those criterion. If using more than one criterion is necessary, ranking is one approach. The use of multiple-criteria MP formulations, however, is also possible and allows the decision maker to specify the characteristics of the selected mix. The results of the multiple-criteria MP demonstrations are described next.

Multiple-criteria Demonstrations

The results of the multiple-criteria MP demonstrations are summarized in tables 14 through 17 (this chapter) and in tables 23 and 24 (Appendix). Tables 14 and 15 compare the mix determined by the ROI model with mixes determined by the single-criterion IP model and by ranking at both budget ceilings. Similarly, tables 16 and 17 compare the results of the sequential GP model with mixes determined by the single-criterion IP model and by ranking at both budget ceilings. Tables 23 and 24 list the related solution mixes and cash flows of the multiple-criteria models at both budget ceilings.

Results of the ROI Model

Rationale for the ROI model is provided in chapter 4 (pp. 76-77). The right-hand-side values for the ROI constraint are the largest ROIs achieved by any of the mixes determined by ranking. From tables 10 and 11, the largest ROIs are 32.6 (at the $73.1 million ceiling) and 21.7 (at the $136.4 million ceiling). These values were achieved when ranking was based on ROI.

Tables 14 and 15 compare the solutions determined by the ROI model with (1) solutions found by the single-criterion IP model and (2) solutions found by ranking at the two budget ceilings. The only difference between the ROI and single-criterion IP models is the additional constraint in the ROI model. The solution mixes of both models were found by IP. Hence, the results of the ROI and single-criterion IP models are listed under the heading "Selection by IP" and are labeled "With ROI" and "Without ROI", respectively.

Perhaps the most interesting comparison in tables 14 and 15 is between the solution mixes found by the ROI model and by ranking, when the ranking criterion is ROI. In terms of the economic indicators listed, the mix found by the ROI

TABLE 14

RESULTS OF THE ROI MODEL

(BUDGET CEILING = $73.1 MILLION)

	Selection by IP		Selection by Ranking		
	With ROI	Without ROI	DoD (as if)	DoD (actual)	ROI [1]
Total in Mix (projects)	39	35	45	42	33
Investment Cost (millions)					
Year 0	72.0	73.1	73.1	73.1	73.1
Year 1	0.7	10.5	0.9	7.2	0.6
Year 2	0.0	11.6	0.0	7.0	0.0
Total	72.7	95.2	74.0	87.3	73.7
Dollar Savings (millions)					
Gross	2370	2502	2248	1946	2403
Net	2297	2407	2174	1859	2329
Labor Savings (manpower positions)					
Authorized	191	180	361	342	186
Equivalent	2483	2502	2834	2419	2428
Total	2674	2682	3195	2761	2614
Economic Indicators					
IRR (%)	154.1	148.8	146.7	134.0	147.4
ROI	32.6	26.3	30.4	22.3	32.6
CPM [2]	27.2	35.5	23.1	31.6	28.2
EPI	13.7	11.7	12.8	10.1	13.5
NPV ($MIL)	925.6	983.9	869.7	778.3	920.2
Opportunity Cost (millions)	58.3	0.0	114.2	205.6	63.7

[1] This mix had the largest ROI (32.6 percent) of any of the mixes determined by ranking.

[2] Cost per manpower space saved (CPM), is calculated by dividing total cost (in thousands of dollars) by total labor savings (authorized and equivalent).

TABLE 15

RESULTS OF THE ROI MODEL

(BUDGET CEILING = $136.4 MILLION)

	Selection by IP		Selection by Ranking	
	With ROI	Without ROI	DoD (as if)	ROI [1]
Total in Mix (projects)	66	74	85	70
Investment Cost (millions)				
Year 0	129.9	136.4	136.3	136.3
Year 1	7.1	15.3	6.0	4.2
Year 2	7.0	11.6	5.1	5.1
Total	144.0	163.3	147.4	145.6
Dollar Savings (millions)				
Gross	3125	3203	3030	3155
Net	2981	3040	2883	3009
Labor Savings (manpower positions)				
Authorized	280	440	456	272
Equivalent	2975	3118	3443	2903
Total	3255	3558	3899	3175
Economic Indicators				
IRR (%)	128.0	125.1	128.9	121.8
ROI	21.7	19.6	20.5	21.7
CPM [2]	44.2	45.9	37.8	45.9
EPI	10.0	9.3	9.6	9.8
NPV ($MIL)	1286.3	1329.6	1262.9	1271.6
Opportunity Cost (millions)	43.3	0.0	66.7	58.0

[1] This mix had the largest ROI (21.7 percent) of any of the mixes determined by ranking.

[2] Cost per manpower space saved (CPM), is calculated by dividing total cost (in thousands of dollars) by total labor savings (authorized and equivalent).

model dominates the mix found by ROI ranking. All of the economic indicators of the solution mix found by the ROI model are equal or superior to the economic indicators of the solution mix found by ROI ranking at both budget ceilings. Most significantly, the ROI model found a mix with the largest ROI achieved by any of the mixes determined by ranking, but with a larger NPV than the mix determined by ROI ranking. At the $73.1 million ceiling, the NPV of the mix determined by the ROI model is $5.4 million more than the NPV of the mix determined by ROI ranking. At the $136.4 million ceiling, the NPV of the mix determined by the ROI model is $4.7 million more than the NPV of the mix determined by ROI ranking. Thus, if achieving some minimum level of ROI is necessary, a MP approach to project selection can be used to maximize the NPV of the mix subject to the ROI and budget constraints.

Similar comparisons with the solution mixes found by the other methods and criteria are possible. For example, at both budget ceilings, the mix found by the ROI model has a larger NPV than the mixes found by the DoD method. Also, the opportunity cost of the ROI model is positive ($58.3 million), but less than the opportunity costs of the DoD methods. If solution mixes with specific minimum levels for ROI are desired, the ROI model can be successfully applied.

Results of the Sequential GP Model

Rationale for the sequential GP model is provided in chapter 4 (pp. 76-78). The right-hand-side values chosen for the three goal constraints are the largest values achieved by any of the mixes determined by ranking or by IP. At the $73.1 million ceiling (table 10), the largest values achieved for authorized labor (La), equivalent labor (Le), and NPV are 464 authorized manpower positions, 3202 equivalent manpower positions, and $983.9 million. At the $136.4 million ceiling (table 11) the largest values achieved for La, Le, and NPV are 509 authorized manpower positions, 3,852 equivalent manpower positions, and $1,329.6 million. The values for La and Le were largest when ranking was based on the CPM criterion; NPV was maximized when IP was used.

Tables 16 and 17 compare the results of the sequential GP model with (1) solutions determined by the single-criterion IP model and (2) several solutions found by ranking at both budget ceilings. The purpose of the sequential GP model is to demonstrate another multiple-criteria MP approach to project selection. In this demonstration, the labor goals were achieved at both budget ceilings. The first priority goal, La, was achieved exactly; the second priority goal, Le, was slightly overachieved. The remaining goal, NPV, was underachieved by $360.4 million at

TABLE 16

RESULTS OF SEQUENTIAL GP MODEL

(BUDGET CEILING = $73.1 MILLION)

	Selection by IP		Selection by Ranking		
	Sequential GP [1]	Single-criterion	DoD (as if)	DoD (actual)	CPM [2]
Total in Mix (projects)	51	35	45	42	55
Investment Cost (millions)					
Year 0	73.1	73.1	73.1	73.1	73.1
Year 1	7.6	10.5	0.9	7.2	0.4
Year 2	5.1	11.6	0.0	7.0	0.0
Total	85.8	95.2	74.0	87.3	73.5
Dollar Savings (millions)					
Gross	1416	2502	2248	1946	1235
Net	1330	2407	2174	1859	1162
Labor Savings (manpower positions)					
Authorized	464	180	361	342	464
Equivalent	3202.3	2502	2834	2419	3201.9
Total	3666.3	2682	3195	2761	3665.9
Economic Indicators					
IRR (%)	134.3	148.8	146.7	134.0	129.2
ROI	16.5	26.3	30.4	22.3	16.8
CPM	23.4	35.5	23.1	31.6	20.1
EPI	8.4	11.7	12.8	10.1	8.3
NPV ($MIL)	623.5	983.9	869.7	778.3	533.8
Opportunity Cost (millions)	360.4	0.0	114.2	205.6	450.1

[1] The first, second and third priority goals are La (464), Le (3201.9), and NPV ($983.9 million), respectively.

[2] This mix had the largest labor savings of any of the mixes determined by ranking.

TABLE 17

RESULTS OF SEQUENTIAL GP MODEL

(BUDGET CEILING = $136.4 MILLION)

	Selection by IP		Selection by Ranking	
	Sequential GP [1]	Single-criterion	DoD (as if)	CPM [2]
Total in Mix (projects)	96	74	85	93
Investment Cost (millions)				
Year 0	136.4	136.4	136.3	136.3
Year 1	9.0	15.3	6.0	2.3
Year 2	5.1	11.6	5.1	0.0
Total	150.5	163.3	147.4	138.6
Dollar Savings (millions)				
Gross	2772	3203	3030	2475
Net	2621	3040	2883	2336
Labor Savings (manpower positions)				
Authorized	509	440	456	509
Equivalent	3852.3	3118	3443	3852.2
Total	4361.3	3558	3899	4361.2
Economic Indicators				
IRR (%)	112.9	125.1	128.9	106.8
ROI	18.4	19.6	20.5	17.8
CPM	34.5	45.9	37.8	31.8
EPI	8.4	9.3	9.6	8.0
NPV ($MIL)	1097.7	1329.6	1262.9	964.5
Opportunity Cost (millions)	231.9	0.0	66.7	365.1

[1] The first, second and third priority goals are La (509), Le (3852.2) and NPV ($1329.6 million), respectively.

[2] This mix had the largest labor savings of any of the mixes determined by ranking.

the $73.1 million ceiling, and by $231.9 million at the $136.4 million ceiling.

These underachieved values ($360.4 million and $231.9 million) represent the opportunity cost of using the three goals to select FY85 PIF projects. The opportunity costs of the mixes found by the DoD method are smaller because achieving a large NPV was assigned a low priority in the sequential GP model. Achieving pre-specified levels of labor savings had a higher priority. This is the essence of sequential GP. Goals are achieved in the priority specified by the decision maker. In this demonstration, the labor savings achieved by the sequential GP model are as large as the labor savings achieved by any of the other methods, including the DoD methods.

Once the labor goals are achieved, the mix with the largest possible NPV is found. Hence, the sequential GP model found mixes with labor savings as large as those found by the CPM mix, but with a larger NPV. At the $73.1 million ceiling, the NPV of the sequential GP mix exceeds the NPV of the CPM mix by $89.7 million; at the $136.4 million ceiling, the NPV of the sequential GP mix exceeds the NPV of the CPM mix by $133.2 million.

Conclusion

This chapter has described the results of applying three MP models to the FY85 PIF capital rationing problem. In the first model, IP was used to maximize the NPV of the solution mix subject to a budget ceiling. The mix determined by IP was compared to six mixes determined by ranking at thirty budget ceilings. Extensive comparisons between the mixes were made at two budget ceilings (\$73.1 million and \$136.4 million) for hypothesis testing. Additional comparisons were made at twenty-eight other budget ceilings to confirm the generalizability of the results. The mixes determined by ranking were based on (1) the DoD method, involving three criteria (IRR, ROI, CPM), and (2) five criteria used separately (IRR, ROI, CPM, NPV, and EPI).

At the two budget ceilings examined in detail, the NPV of the mix selected by IP was larger than the NPV of the mix found by any ranking strategy, including the DoD method. For example, at the \$73.1 million ceiling, the NPV of the mix determined by IP exceeded the NPV of the mix actually funded by \$205.6 million. Therefore, the hypothesis is confirmed.

In addition, the economic superiority of the IP-based mix was demonstrated over broad ranges of budget ceilings and discount rates. The feasibility and economic desirability of the single-criterion model are apparent. Integer solutions to the single-criterion MP model were found within fifteen seconds (of central processing urit time) at the thirty budget ceilings tested. The average opportunity cost of ranking ranged from \$23 million to \$242 million, depending on the ranking criterion or method used.

In the multiple-criteria MP demonstrations, the mixes found by the MP models were also economically superior to those found by ranking, when pre-specified objectives (involving minimum levels of ROI and labor savings) were set for the solution mix. For example, the mix with the largest ROI was found when ranking was based on the ROI criterion; however, the ROI model found a mix with the same ROI, but with a larger NPV. Similarly, the sequential GP model found a mix with labor savings as large as those found by any of the mixes determined by ranking, but with a larger NPV than the relevant ranking-based mix.

The goals, targets, and relative priorities for the multiple-criteria MP models were chosen as examples. Other goals, targets, and/or priorities are possible. However, the intention is to demonstrate the feasibility of using multiple-criteria MP models to select PIF projects. Therefore, no additional examples are necessary; the feasibility and economic desirability of the multiple-criteria MP models are established. Integer solutions required less than thirty seconds (of central processing unit time) at the two budget levels tested. The multiple-criteria MP models allow the decision maker to shape the characteristics of the PIF solution mix according to any number of goals or criteria.

In chapter 6, the entire study is summarized. Potential extensions of the study are described.

CHAPTER 6

SUMMARY, CONCLUSION, AND SUGGESTIONS FOR FUTURE RESEARCH

Summary

The application of mathematical programming (MP) to the Department of Defense (DoD) Productivity Investment Fund (PIF) capital rationing problem is both appropriate and feasible. An optimizing approach to project selection is consistent with the intent of the PIF program. The DoD currently uses ranking to select PIF projects. Ranking is not an optimizing approach and does not identify the optimal economic mix. As demonstrated in this study, substantial dollar savings are likely if MP is used instead of ranking.

As explained in chapter 2 (pp. 10-12), the PIF program was established to achieve economy and efficiency in the DoD by providing funds for economically attractive projects. Each year, the total cost of eligible projects submitted by DoD components exceeds the amount of PIF money available. Accordingly, the projects must compete for the scarce resources. After an extensive screening process, in which the feasibility and accuracy of each project is evaluated at several organizational levels within the DoD, project selection becomes entirely objective, involving a ranking strategy based on several economic criteria chosen by the Defense

Productivity Program Office (DPPO) under the direction of the Office of the Secretary of Defense (OSD).

While ranking is certainly objective and easy to apply, the method does not always identify the optimal economic mix: the net present value (NPV) of the portfolio of projects identified by ranking is not maximized. Ranking can result in suboptimal economic choices because the method is essentially a heuristic that is not capable of adequately adjusting for (1) the existence of multiple, usually contradictory selection criteria, (2) multi-period budgets, and (3) projects that are indivisible and/or interdependent.

Instead of selecting projects by ranking, MP can be used. MP is certainly as objective as ranking--either selection method is accomplished by computer and is applied at the same stage in the PIF selection process. Also, MP is as easy to apply as ranking--both procedures use a computer, are based on the same data, and can use the same selection criteria. While the MP approach typically requires a mainframe computer for large-scale problems, this should not be a serious impediment, especially when the dollar magnitude of the PIF program is considered. In Fiscal Year 1985 (FY85), the PIF budget ceiling was $136.4 million; the life-cycle savings (gross) of the competing FY85 PIF projects were $4 billion. Finally, MP is an exact approach that can overcome the limitations of ranking and identify the optimal economic mix. As suggested by several simulation studies referenced in chapter two (p. 24), a marginally superior mix of projects identified by the MP approach is justified when the dollar magnitude of the capital rationing problem is large.

There are, however, several theoretical issues and practical limitations that make the successful application of MP to large-scale capital rationing problems uncertain. As described in chapter 3, these issues and limitations involve (1) the choice of the appropriate discount rate, (2) the existence of multiple objectives in the capital rationing decision, (3) the nondeterministic nature of the data, and (4) the computational efficiency of existing integer programming (IP) algorithms needed for integer solutions to the MP formulations.

These issues and limitations can be resolved by a careful analysis of the exact capital rationing problem. This was accomplished in chapters three and four. In chapter three, the extensive literature treating these issues and limitations was reviewed; potential solutions were identified. In chapter four, each issue and limitation was considered in the context of the PIF program to identify and rationalize three MP formulations.

For the PIF capital rationing problem, a present value formulation is appropriate, with NPV as the single-criterion maximand determined at the DoD's ten percent cost of capital. No formal adjustment for risk was made in the MP formulations of this study because (1) a four-year payback period is enforced on all PIF candidates, (2) the DoD discount rate already includes a risk premium, and (3) data needed for formal adjustments are not presently available. In addition to the single-criterion MP model, two multiple-criteria models were developed to demonstrate how multiple criteria or objectives can be used in MP formulations to select PIF projects. Details on the research design, methodology, parameters, PIF database, hardware, and software used by the three models were described and defended in chapter 4.

Chapter 5 presents the results of applying the three MP models to 186 PIF projects that competed for funding in FY85. In the first model, the NPV of the optimal economic mix (determined by MP) exceeded the NPV of any mix determined by ranking, including the DoD method. The opportunity cost of ranking, defined as the difference between the IP-based and ranking-based mixes, was nonnegative at every budget level examined and at all reasonable discount rates. For example, when the budget ceiling was set at the level allocated to the FY85 PIF program (before subtracting the cost of previously approved PIF projects), the opportunity cost of the DoD method was $66.7 million; when the budget ceiling was set at the cost (first-year) of PIF projects actually funded in FY85, the opportunity cost of the DoD selection method was $205.6 million. Therefore, substantial dollar savings are likely if projects are identified by MP instead of by ranking.

In the multiple-criteria MP demonstrations, the mixes found by the two MP models were also economically superior to those found by ranking, when pre-specified objectives (involving minimum levels for return on investment and labor savings) were set for the solution mix. The multiple-criteria models will likely not find the optimal economic mix; however, if a satisficing approach to project selection is necessary, MP can still be used to maximize the NPV of the solution mix subject to any number of objectives or criteria desired by the decision maker. Thus, the multiple-criteria MP models afford the decision maker a degree of control over the solution mix that is not possible with ranking.

Conclusion

The use of MP to select PIF projects will result in substantial dollar savings to the DoD. The current method is a heuristic that is easy to use and objective, but no more so than MP. Using MP in realistic capital rationing problems may have once been seriously impaired by the issues and limitations described in this study; this should no longer be the case. Given the economic objective of the PIF program, and the capability of MP to find the optimal economic mix, the continued use of the present selection method is inconsistent, irrational and wasteful. In the words of Nobel laureate Herbert Simon, "no one in his right mind will satisfice if he can equally well optimize" (1969, p. 64).

As expected, the contributions of this study are largely practical. First, substantial dollar savings are likely if the DoD uses the MP approach to select PIF projects. Second, the study describes the successful application of MP to a real life capital rationing problem. Accordingly, the study should encourage the increased use of MP in similar problems. Finally, the study begins to fill the void of applied capital budgeting research in management accounting literature identified by Klemstine and Maher (1983). Demski and Kreps (1983) and Kaplan (1984) have challenged accounting researchers to study and report on actual management decision problems; this study is a response to that challenge.

Suggestions for Future Research

There are a number of possible extensions to this study. Perhaps the most obvious extension is a replication using PIF data from a different year. The DPPO maintains a fairly complete database on PIF projects submitted since Fiscal Year 1982 (FY82). For this study, FY85 data were used. A replication using data from other years would aid in verifying the results.

In addition to a replication, another possible extension involves determining the optimal annual level of expenditure in the PIF program. Currently, the DoD selects projects until the PIF budget is exhausted. Meeting the budget exactly is an understandable practice in the government because both overspending and underspending can result in reduced future budgets (Zimmerman, 1976). However, if the DoD could hold large amounts of PIF money over to future years without penalty, increased savings may be possible. Instead of maximizing the NPV of a mix subject to a given budget ceiling, it may be possible to determine the optimal level of the budget(s) and the mix simultaneously. Zeleny (1981, 1984) describes a MP technique, termed "de novo programming," that does this. Assuming that the last several years of PIF data are fairly representative of future PIF projects, applying de novo programming to PIF data from FY82 to the present would be an interesting extension.

This study may also be extended through more formal adjustments for risk. A post-audit of PIF projects was recommended by General Management Systems (1986, p. 111). When post-audit data become available, exploring the use of chance constraints, stochastic or quadratic MP models may be possible (chapter 3, pp. 51-53). Alternatively, post-audit data on approved PIF projects could be used to evaluate the relative riskiness of candidate projects of the same type. A schedule of risk premiums could (conceivably) be established, in which those projects judged most risky are assigned the largest premiums (Sundem, 1974). In this way, competing projects are assigned to appropriate risk classes and discounted accordingly. Any of the MP formulations described in this study can accomodate different discount rates. There is no reason why a schedule of rates reflecting various risk classes could not be subjectively established and applied.

Extensions involving the multiple-criteria MP models are also possible. Other goals, targets, and priorities can be used. Also, the two interactive models demonstrated in this study could be transformed into noninteractive (automatic models). For example, in the sequential GP model used in this study, the user adds appropriate system constraints reflecting the sequential achievement of goals. An automatic procedure that does not require the user's intervention may be more desirable. Automatic GP models capable of handling large-scale capital rationing problems are reported in the academic literature (e.g., Ignizio, 1980, 1985b, 1985c). In another example, a fuzzy programming model (chapter 3, pp. 50-51) of the PIF capital rationing problem may also be possible. These models were not used in this study because they were not readily available. Also, the two models tested in this study are illustrative, not exhaustive demonstrations of the multiple-criteria MP approach to project selection.

APPENDIX

TABLE 18 PIF PROJECT DATA

Project:	1	2	3	4	5	6
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	2180.7	472.8	16066.4	697.8	1082.8	18110.9
2	2180.7	472.8	16202.2	679.9	1082.8	18110.9
3	2180.7	472.8	16202.2	679.9	1082.8	18110.9
4	2180.7	472.8	16202.2	679.9	1082.8	18110.9
5	2180.7	472.8	16202.2	679.9	1082.8	18110.9
6	2180.7	472.8	0.0	679.9	1082.8	18110.9
7	2180.7	472.8	0.0	679.9	1082.8	18110.9
8	2180.7	472.8	0.0	679.9	1082.8	18110.9
9	2180.7	472.8	0.0	679.9	1082.8	18110.9
10	2180.7	472.8	0.0	679.9	1082.8	18110.9
11	2180.7	472.8	0.0	0.0	1082.8	18110.9
12	2180.7	472.8	0.0	0.0	1082.8	18110.9
13	2180.7	472.8	0.0	0.0	1082.8	18110.9
14	2180.7	472.8	0.0	0.0	1082.8	18110.9
15	2180.7	472.8	0.0	0.0	0.0	18110.9
16	0.0	472.8	0.0	0.0	0.0	18110.9
17	0.0	472.8	0.0	0.0	0.0	18110.9
18	0.0	472.8	0.0	0.0	0.0	18110.9
19	0.0	472.8	0.0	0.0	0.0	18110.9
20	0.0	472.8	0.0	0.0	0.0	18110.9
21	0.0	0.0	0.0	0.0	0.0	18110.9
22	0.0	0.0	0.0	0.0	0.0	18110.9
23	0.0	0.0	0.0	0.0	0.0	18110.9
24	0.0	0.0	0.0	0.0	0.0	18110.9
25	0.0	0.0	0.0	0.0	0.0	18110.9
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	476.1	128.0	2553.0	260.8	600.0	12800.0
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	0.0	120.0	0.0	0.0	0.0	0.0
Equi.	147.9	0.3	490.9	22.4	72.0	650.0
Criteria						
IRR	458.0	369.4	630.0	265.7	180.5	141.5
ROI	68.7	73.9	31.7	26.1	25.3	35.4
CPM	3.2	1.1	5.2	11.6	8.3	19.7
NPV	16.111	3.897	58.743	3.933	7.377	151.593
EPI	34.8	31.5	24.0	16.1	13.3	12.8

Project:	7	8	9	10	11	12
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	569.0	1612.0	1007.5	4289.4	5338.2	2598.5
2	2275.0	1612.0	1007.5	4289.4	5338.2	2598.5
3	6845.0	1612.0	1007.5	4289.4	5338.2	2598.5
4	14788.0	1612.0	1007.5	4289.4	5338.2	2598.5
5	22750.0	1612.0	1007.5	4289.4	5338.2	2598.5
6	0.0	1612.0	1007.5	4289.4	5338.2	0.0
7	0.0	1612.0	1007.5	4289.4	5338.2	0.0
8	0.0	1612.0	1007.5	4289.4	5338.2	0.0
9	0.0	1612.0	0.0	4289.4	5338.2	0.0
10	0.0	1612.0	0.0	4289.4	5338.2	0.0
11	0.0	1612.0	0.0	4289.4	5338.2	0.0
12	0.0	1612.0	0.0	4289.4	5338.2	0.0
13	0.0	1612.0	0.0	4289.4	5338.2	0.0
14	0.0	1612.0	0.0	4289.4	5338.2	0.0
15	0.0	1612.0	0.0	4289.4	5338.2	0.0
16	0.0	1612.0	0.0	4289.4	0.0	0.0
17	0.0	1612.0	0.0	4289.4	0.0	0.0
18	0.0	1612.0	0.0	4289.4	0.0	0.0
19	0.0	1612.0	0.0	4289.4	0.0	0.0
20	0.0	1612.0	0.0	4289.4	0.0	0.0
21	0.0	1612.0	0.0	4289.4	0.0	0.0
22	0.0	1612.0	0.0	4289.4	0.0	0.0
23	0.0	1612.0	0.0	4289.4	0.0	0.0
24	0.0	1612.0	0.0	4289.4	0.0	0.0
25	0.0	1612.0	0.0	4289.4	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	1958.0	998.0	340.5	3113.0	3864.0	1072.6
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	0.0	28.0	0.0	0.0	0.0	0.0
Equi.	415.0	0.0	8.5	154.0	205.8	58.2
Criteria						
IRR	136.0	161.5	295.9	137.8	138.2	241.7
ROI	24.1	40.4	23.7	34.5	20.7	12.1
CPM	4.7	35.6	40.1	20.2	18.8	18.4
NPV	29.809	13.634	5.034	35.822	36.739	8.778
EPI	16.2	14.7	15.8	12.5	10.5	9.2

Project:	13	14	15	16	17	18
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	236.0	1336.9	640.6	426.2	2205.5	6537.0
2	236.0	1268.4	886.7	405.2	2205.5	6537.0
3	236.0	1268.4	886.7	405.2	2205.5	6537.0
4	236.0	1268.4	886.7	405.2	2205.5	6537.0
5	236.0	1268.4	886.7	405.2	2205.5	6537.0
6	236.0	1268.4	886.7	405.2	0.0	6537.0
7	236.0	1268.4	886.7	405.2	0.0	6537.0
8	236.0	1268.4	886.7	405.2	0.0	6537.0
9	236.0	0.0	886.7	0.0	0.0	0.0
10	236.0	0.0	886.7	0.0	0.0	0.0
11	236.0	0.0	0.0	0.0	0.0	0.0
12	236.0	0.0	0.0	0.0	0.0	0.0
13	236.0	0.0	0.0	0.0	0.0	0.0
14	236.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	165.0	563.5	608.1	221.4	1169.0	4822.0
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	5.0	0.0	0.0	0.0	0.0	15.0
Equi.	0.0	10.2	30.7	3.8	51.9	216.0
Criteria						
IRR	143.0	233.6	123.4	189.2	187.7	135.4
ROI	20.0	18.1	14.2	14.7	9.4	10.9
CPM	33.0	55.2	19.8	58.3	22.5	20.7
NPV	1.574	6.266	4.617	1.959	7.192	30.052
EPI	10.5	12.1	8.6	9.9	7.2	7.2

Project:	19	20	21	22	23	24
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	245.0	625.4	129.6	0.0	0.0	3646.0
2	245.0	478.3	129.0	16280.9	2922.4	3646.0
3	245.0	478.3	129.0	21707.9	3107.4	3646.0
4	245.0	478.3	129.0	21707.9	3117.1	3646.0
5	245.0	478.3	129.0	21707.9	3221.8	3646.0
6	245.0	478.3	129.0	21707.9	3331.7	0.0
7	245.0	478.3	129.0	21707.9	3447.2	0.0
8	245.0	478.3	129.0	21707.9	3568.4	0.0
9	245.0	478.3	129.0	21707.9	0.0	0.0
10	245.0	478.3	129.0	21707.9	0.0	0.0
11	245.0	478.3	0.0	21707.9	0.0	0.0
12	245.0	478.3	0.0	21707.9	0.0	0.0
13	245.0	0.0	0.0	21707.9	0.0	0.0
14	245.0	0.0	0.0	21707.9	0.0	0.0
15	245.0	0.0	0.0	21707.9	0.0	0.0
16	245.0	0.0	0.0	21707.9	0.0	0.0
17	245.0	0.0	0.0	21707.9	0.0	0.0
18	245.0	0.0	0.0	21707.9	0.0	0.0
19	245.0	0.0	0.0	21707.9	0.0	0.0
20	0.0	0.0	0.0	21707.9	0.0	0.0
21	0.0	0.0	0.0	21707.9	0.0	0.0
22	0.0	0.0	0.0	21707.9	0.0	0.0
23	0.0	0.0	0.0	21707.9	0.0	0.0
24	0.0	0.0	0.0	21707.9	0.0	0.0
25	0.0	0.0	0.0	21707.9	0.0	0.0
26	0.0	0.0	0.0	21707.9	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	270.0	503.7	114.1	10729.0	822.4	2715.0
1	0.0	0.0	0.0	0.0	602.3	10.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	10.0	13.0	0.0	0.0	0.0	120.0
Equi.	0.0	0.0	2.1	119.0	13.5	2.0
Criteria						
IRR	90.7	110.3	113.3	92.5	123.4	132.1
ROI	17.2	11.7	11.3	50.1	15.9	6.7
CPM	27.0	38.7	54.3	90.2	105.5	22.3
NPV	1.779	2.889	0.679	163.916	12.824	11.097
EPI	7.6	6.7	7.0	16.3	10.4	5.1

Project:	25	26	27	28	29	30
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	187.8	316.6	700.0	2469.0	694.0	225.0
2	187.8	262.6	700.0	1490.0	1388.0	235.0
3	187.8	262.6	700.0	1490.0	1388.0	250.0
4	187.8	262.6	700.0	1490.0	1388.0	250.0
5	187.8	262.6	700.0	1490.0	1388.0	250.0
6	187.8	0.0	700.0	1490.0	1388.0	250.0
7	187.8	0.0	700.0	1490.0	1388.0	250.0
8	187.8	0.0	700.0	1490.0	1388.0	250.0
9	187.8	0.0	700.0	0.0	1388.0	250.0
10	187.8	0.0	700.0	0.0	1388.0	250.0
11	0.0	0.0	0.0	0.0	694.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	207.0	215.4	145.0	1480.2	1100.0	199.0
1	0.0	0.0	0.0	264.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	3.0	10.0	0.0	0.0	5.0	0.0
Equi.	3.1	0.9	0.0	48.9	9.0	2.0
Criteria						
IRR	90.6	134.6	482.8	127.6	95.3	116.9
ROI	9.1	6.4	48.3	7.4	12.6	12.4
CPM	33.9	19.8	9999.0	35.7	78.6	99.5
NPV	0.947	0.829	4.156	7.119	7.041	1.302
EPI	5.6	4.9	29.7	5.1	7.4	7.5

TABLE 18 (Continued)

Project:	31	32	33	34	35	36
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	175.3	1213.3	1068.1	4200.0	1027.0	2648.6
2	175.3	1213.3	1068.1	4140.0	1027.0	2648.6
3	175.3	1213.3	1068.1	4140.0	1027.0	2648.6
4	175.3	1213.3	1068.1	4140.0	1027.0	2648.6
5	175.3	1213.3	1068.1	4140.0	1027.0	2648.6
6	175.3	1213.3	1068.1	4140.0	1027.0	2648.6
7	175.3	1213.3	1068.1	4140.0	1027.0	2648.6
8	175.3	1213.3	1068.1	4140.0	1027.0	2648.6
9	175.3	0.0	0.0	4140.0	1027.0	2648.6
10	175.3	0.0	0.0	4140.0	1027.0	2648.6
11	0.0	0.0	0.0	0.0	1027.0	2648.6
12	0.0	0.0	0.0	0.0	1027.0	2648.6
13	0.0	0.0	0.0	0.0	1027.0	2648.6
14	0.0	0.0	0.0	0.0	1027.0	2648.6
15	0.0	0.0	0.0	0.0	1027.0	2648.6
16	0.0	0.0	0.0	0.0	0.0	2648.6
17	0.0	0.0	0.0	0.0	0.0	2648.6
18	0.0	0.0	0.0	0.0	0.0	2648.6
19	0.0	0.0	0.0	0.0	0.0	2648.6
20	0.0	0.0	0.0	0.0	0.0	2648.6
21	0.0	0.0	0.0	0.0	0.0	2648.6
22	0.0	0.0	0.0	0.0	0.0	2648.6
23	0.0	0.0	0.0	0.0	0.0	2648.6
24	0.0	0.0	0.0	0.0	0.0	2648.6
25	0.0	0.0	0.0	0.0	0.0	2648.6
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	125.5	900.3	254.3	1134.9	392.0	1207.4
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	0.0	0.0	0.0	0.0	0.0	0.0
Equi.	0.8	10.2	0.0	0.0	0.0	0.0
Criteria						
IRR	139.7	134.6	420.0	368.9	262.0	219.4
ROI	14.0	10.8	33.6	36.5	39.3	54.8
CPM	156.9	88.3	9999.0	9999.0	9999.0	9999.0
NPV	0.952	5.573	5.444	24.358	7.419	22.834
EPI	8.6	7.2	22.4	22.5	19.9	19.9

Project:	37	38	39	40	41	42
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	300.0	0.0	0.0	887.3	881.8
2	22798.4	600.0	1200.0	1860.9	887.3	881.8
3	16331.4	750.0	1200.0	1860.9	887.3	881.8
4	16331.4	750.0	1200.0	1860.9	887.3	881.8
5	16331.4	750.0	1200.0	1860.9	887.3	881.8
6	16331.4	750.0	1200.0	1860.9	887.3	881.8
7	16331.4	750.0	1200.0	1860.9	887.3	881.8
8	16331.4	750.0	1200.0	1860.9	887.3	881.8
9	16331.4	750.0	1200.0	1860.9	887.3	881.8
10	16331.4	750.0	1200.0	1860.9	887.3	881.8
11	16331.4	750.0	1200.0	1860.9	0.0	0.0
12	16331.4	750.0	1200.0	0.0	0.0	0.0
13	16331.4	750.0	1200.0	0.0	0.0	0.0
14	16331.4	750.0	1200.0	0.0	0.0	0.0
15	16331.4	750.0	1200.0	0.0	0.0	0.0
16	16331.4	0.0	1200.0	0.0	0.0	0.0
17	16331.4	0.0	1200.0	0.0	0.0	0.0
18	16331.4	0.0	1200.0	0.0	0.0	0.0
19	16331.4	0.0	1200.0	0.0	0.0	0.0
20	16331.4	0.0	0.0	0.0	0.0	0.0
21	16331.4	0.0	0.0	0.0	0.0	0.0
22	16331.4	0.0	0.0	0.0	0.0	0.0
23	16331.4	0.0	0.0	0.0	0.0	0.0
24	16331.4	0.0	0.0	0.0	0.0	0.0
25	16331.4	0.0	0.0	0.0	0.0	0.0
26	16331.4	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	10978.0	875.0	280.7	464.9	949.3	338.5
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	0.0	15.0	0.0	0.0	0.0	0.0
Equi.	63.0	5.0	0.0	0.4	12.0	0.0
Criteria						
IRR	92.1	61.9	162.7	156.2	93.3	260.5
ROI	37.8	12.2	77.0	40.0	9.4	26.1
CPM	174.3	43.8	9999.0	1162.3	79.1	9999.0
NPV	129.131	4.297	8.666	9.930	4.503	5.080
EPI	12.8	5.9	31.9	22.4	5.7	16.0

Project:	43	44	45	46	47	48
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	100.0	0.0	0.0
1	0.0	295.7	4500.7	300.0	630.0	0.0
2	55502.0	309.7	4500.7	300.0	630.0	1800.0
3	13336.0	324.9	4500.7	300.0	690.0	1800.0
4	23634.0	341.7	4500.7	300.0	690.0	1800.0
5	14020.0	341.7	4500.7	300.0	690.0	1800.0
6	2491.2	341.7	4500.7	300.0	0.0	1800.0
7	2491.2	341.7	4500.7	300.0	0.0	1800.0
8	2491.2	341.7	4500.7	300.0	0.0	1800.0
9	2491.2	0.0	4500.7	300.0	0.0	1800.0
10	2491.2	0.0	4500.7	300.0	0.0	1800.0
11	2491.2	0.0	4500.7	300.0	0.0	1800.0
12	2491.2	0.0	4500.7	300.0	0.0	0.0
13	2491.2	0.0	4500.7	300.0	0.0	0.0
14	2491.2	0.0	4500.7	300.0	0.0	0.0
15	2491.2	0.0	4500.7	300.0	0.0	0.0
16	2491.2	0.0	0.0	300.0	0.0	0.0
17	2491.2	0.0	0.0	300.0	0.0	0.0
18	2491.2	0.0	0.0	300.0	0.0	0.0
19	2491.2	0.0	0.0	300.0	0.0	0.0
20	2491.2	0.0	0.0	200.0	0.0	0.0
21	2491.2	0.0	0.0	0.0	0.0	0.0
22	2491.2	0.0	0.0	0.0	0.0	0.0
23	2491.2	0.0	0.0	0.0	0.0	0.0
24	2491.2	0.0	0.0	0.0	0.0	0.0
25	2491.2	0.0	0.0	0.0	0.0	0.0
26	2491.2	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	8961.0	350.0	2163.3	505.0	202.0	1691.0
1	0.0	0.0	0.0	0.0	50.0	0.0
2	0.0	0.0	0.0	0.0	25.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	17.0	8.0	0.0	5.0	0.0	26.0
Equi.	0.0	0.0	0.0	0.8	0.2	0.0
Criteria						
IRR	168.4	87.9	208.0	74.1	292.6	64.3
ROI	17.7	7.5	31.2	11.9	12.0	10.6
CPM	527.1	43.8	9999.0	87.1	1385.0	65.0
NPV	85.154	1.392	32.069	2.134	2.243	8.364
EPI	10.5	5.0	15.8	5.2	9.4	6.0

Project:	49	50	51	52	53	54
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	1015.3	781.6	569.0	8855.5	67.3	67.3
2	924.3	781.6	848.0	8855.5	67.3	67.3
3	924.3	781.6	1118.0	8855.5	67.3	67.3
4	924.3	781.6	1434.8	8855.5	67.3	67.3
5	924.3	781.6	1654.4	8855.5	67.3	67.3
6	924.3	781.6	1883.0	0.0	67.3	67.3
7	924.3	781.6	2124.2	0.0	67.3	67.3
8	924.3	781.6	2378.0	0.0	67.3	67.3
9	0.0	781.6	2444.4	0.0	67.3	67.3
10	0.0	781.6	2923.4	0.0	67.3	67.3
11	0.0	781.6	0.0	0.0	0.0	0.0
12	0.0	781.6	0.0	0.0	0.0	0.0
13	0.0	781.6	0.0	0.0	0.0	0.0
14	0.0	781.6	0.0	0.0	0.0	0.0
15	0.0	781.6	0.0	0.0	0.0	0.0
16	0.0	781.6	0.0	0.0	0.0	0.0
17	0.0	781.6	0.0	0.0	0.0	0.0
18	0.0	781.6	0.0	0.0	0.0	0.0
19	0.0	781.6	0.0	0.0	0.0	0.0
20	0.0	781.6	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	911.0	1072.4	2101.0	8480.0	109.0	109.0
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	0.0	6.0	20.0	0.0	4.0	4.0
Equi.	8.5	1.9	125.8	187.0	4.0	4.0
Criteria						
IRR	106.3	72.9	49.7	101.3	61.2	61.2
ROI	8.2	14.6	8.3	5.2	6.2	6.2
CPM	107.2	135.7	14.4	45.3	13.6	13.6
NPV	4.103	5.582	7.390	25.089	0.305	0.305
EPI	5.5	6.2	4.5	4.0	3.8	3.8

Project:	55	56	57	58	59	60
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	173.0	0.0	0.0
1	133.0	1267.1	401.8	231.0	416.0	11657.6
2	133.0	1253.2	401.8	231.0	642.3	15539.4
3	133.0	1253.2	401.8	231.0	658.6	19439.4
4	133.0	1253.2	401.8	231.0	658.6	25239.4
5	133.0	1253.2	401.8	231.0	658.6	25239.4
6	133.0	1253.2	401.8	231.0	658.6	25239.4
7	133.0	1253.2	401.8	231.0	658.6	25239.4
8	133.0	1253.2	401.8	231.0	658.6	25239.4
9	133.0	1253.2	0.0	231.0	658.6	0.0
10	133.0	1253.2	0.0	231.0	658.6	0.0
11	133.0	0.0	0.0	0.0	0.0	0.0
12	133.0	0.0	0.0	0.0	0.0	0.0
13	133.0	0.0	0.0	0.0	0.0	0.0
14	133.0	0.0	0.0	0.0	0.0	0.0
15	133.0	0.0	0.0	0.0	0.0	0.0
16	133.0	0.0	0.0	0.0	0.0	0.0
17	133.0	0.0	0.0	0.0	0.0	0.0
18	133.0	0.0	0.0	0.0	0.0	0.0
19	133.0	0.0	0.0	0.0	0.0	0.0
20	133.0	0.0	0.0	0.0	0.0	0.0
21	133.0	0.0	0.0	0.0	0.0	0.0
22	133.0	0.0	0.0	0.0	0.0	0.0
23	133.0	0.0	0.0	0.0	0.0	0.0
24	133.0	0.0	0.0	0.0	0.0	0.0
25	133.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	191.7	1159.9	418.0	405.0	909.9	14132.5
1	0.0	0.0	0.0	45.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	0.0	0.0	0.0	0.0	0.0	0.0
Equi.	1.0	3.3	3.2	9.0	21.4	23.1
Criteria						
IRR	69.4	108.6	95.7	90.2	61.2	106.4
ROI	17.3	10.8	7.7	5.5	7.0	12.2
CPM	191.7	351.5	130.6	50.0	42.5	611.8
NPV	1.015	6.553	1.726	1.147	2.903	95.797
EPI	6.3	6.7	5.1	3.6	4.2	7.8

TABLE 18 (Continued)

Project:	61	62	63	64	65	66
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	1327.2	3093.4	461.0	1796.3	2471.8	3392.5
2	1327.2	3093.4	449.6	1728.2	2409.6	369.0
3	1327.2	3093.4	449.6	1728.2	2409.6	369.0
4	1327.2	3093.4	449.6	1728.2	2409.6	369.0
5	1327.2	3093.4	449.6	1728.2	2409.6	369.0
6	1327.2	3093.4	449.6	1728.2	2409.6	369.0
7	1327.2	3093.4	449.6	1728.2	2409.6	369.0
8	1327.2	3093.4	449.6	1728.2	2409.6	369.0
9	1327.2	0.0	0.0	1728.2	0.0	369.0
10	1327.2	0.0	0.0	1728.2	0.0	369.0
11	0.0	0.0	0.0	0.0	0.0	369.0
12	0.0	0.0	0.0	0.0	0.0	369.0
13	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	995.5	3138.0	471.0	2018.5	3352.9	1181.3
1	0.0	0.0	0.0	0.0	0.0	142.6
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	0.0	0.0	0.0	0.0	0.0	7.0
Equi.	0.0	18.9	3.1	12.7	78.3	0.0
Criteria						
IRR	133.3	98.2	96.2	87.0	71.7	191.4
ROI	13.3	7.9	7.7	8.6	5.8	5.6
CPM	9999.0	166.0	151.9	158.9	42.8	189.1
NPV	7.160	13.365	1.938	8.662	9.559	3.952
EPI	8.2	5.3	5.1	5.3	3.9	4.0

Project:	67	68	69	70	71	72
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	830.2	110.8	0.0	52.2	1159.3	108.0
2	830.2	110.8	3813.0	52.1	2397.6	123.0
3	830.2	110.8	7761.5	52.1	2480.5	139.0
4	830.2	110.8	7966.0	52.1	2567.5	160.0
5	830.2	110.8	8153.7	52.1	2658.9	179.0
6	830.2	110.8	8406.2	52.1	2754.8	203.0
7	830.2	110.8	8642.9	52.1	2855.6	230.0
8	830.2	110.8	8891.6	52.1	2961.4	259.0
9	830.2	110.8	9152.7	52.1	0.0	0.0
10	830.2	110.8	9426.6	52.1	0.0	0.0
11	830.2	0.0	9714.1	52.1	0.0	0.0
12	830.2	0.0	0.0	52.1	0.0	0.0
13	830.2	0.0	0.0	52.1	0.0	0.0
14	830.2	0.0	0.0	52.1	0.0	0.0
15	830.2	0.0	0.0	52.1	0.0	0.0
16	830.2	0.0	0.0	52.1	0.0	0.0
17	830.2	0.0	0.0	52.1	0.0	0.0
18	830.2	0.0	0.0	52.1	0.0	0.0
19	830.2	0.0	0.0	52.1	0.0	0.0
20	830.2	0.0	0.0	52.1	0.0	0.0
21	830.2	0.0	0.0	52.1	0.0	0.0
22	830.2	0.0	0.0	52.1	0.0	0.0
23	830.2	0.0	0.0	52.1	0.0	0.0
24	830.2	0.0	0.0	52.1	0.0	0.0
25	830.2	0.0	0.0	52.1	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	1800.0	134.2	500.0	129.7	1641.3	157.0
1	0.0	0.0	3500.0	0.0	1136.5	0.0
2	0.0	0.0	5109.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	4.0	0.0	0.0	0.0	10.0	0.0
Equi.	21.0	1.0	34.0	2.0	10.4	0.6
Criteria						
IRR	46.1	82.4	84.4	40.2	82.6	80.7
ROI	11.5	8.3	9.0	10.0	7.1	8.9
CPM	72.0	134.2	267.9	64.9	136.2	261.7
NPV	5.736	0.547	35.831	0.343	10.031	0.721
EPI	4.2	5.1	5.5	3.7	4.8	5.6

Project:	73	74	75	76	77	78
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	14404.6	173.3	1075.0	546.1	76.2	200.4
2	12890.8	173.3	3263.0	546.1	76.2	200.4
3	12890.8	173.3	3223.0	546.1	76.2	200.4
4	12890.8	173.3	3226.0	546.1	76.2	200.4
5	12890.8	173.3	3223.0	546.1	76.2	200.4
6	0.0	173.3	3223.0	546.1	76.2	200.4
7	0.0	173.3	3223.0	546.1	76.2	200.4
8	0.0	173.3	3263.0	546.1	76.2	200.4
9	0.0	0.0	3235.0	0.0	76.2	0.0
10	0.0	0.0	3263.0	0.0	76.2	0.0
11	0.0	0.0	3222.0	0.0	76.2	0.0
12	0.0	0.0	3222.0	0.0	76.2	0.0
13	0.0	0.0	3222.0	0.0	0.0	0.0
14	0.0	0.0	3225.0	0.0	0.0	0.0
15	0.0	0.0	3218.0	0.0	0.0	0.0
16	0.0	0.0	3215.0	0.0	0.0	0.0
17	0.0	0.0	3215.0	0.0	0.0	0.0
18	0.0	0.0	3215.0	0.0	0.0	0.0
19	0.0	0.0	3227.0	0.0	0.0	0.0
20	0.0	0.0	3245.0	0.0	0.0	0.0
21	0.0	0.0	3215.0	0.0	0.0	0.0
22	0.0	0.0	3255.0	0.0	0.0	0.0
23	0.0	0.0	3215.0	0.0	0.0	0.0
24	0.0	0.0	3218.0	0.0	0.0	0.0
25	0.0	0.0	3215.0	0.0	0.0	0.0
26	0.0	0.0	3215.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	15529.8	210.0	4900.0	575.0	142.2	305.0
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	0.0	0.0	0.0	0.0	1.0	0.0
Equi.	256.0	1.5	17.3	1.7	1.2	4.5
Criteria						
IRR	83.4	81.8	51.2	94.5	53.3	64.5
ROI	4.3	6.6	16.7	7.6	6.4	5.3
CPM	60.7	140.0	283.2	338.2	64.6	67.8
NPV	34.713	0.715	22.745	2.338	0.377	0.764
EPI	3.2	4.4	5.6	5.1	3.7	3.5

TABLE 18 (Continued)

Project:	79	80	81	82	83	84
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	121.8	104.2	955.0	2131.6	4952.3	1882.9
2	121.8	104.0	955.0	2131.6	5929.2	8809.0
3	121.8	104.0	955 0	2131.6	6878.7	9458.2
4	121.8	104.0	955.0	2131.6	6878.7	9458.2
5	121.8	104.0	955.0	2131.6	6878.7	8907.7
6	121.8	104.0	955.0	2131.6	6878.7	7256.4
7	121.8	104.0	0.0	2131.6	6878.7	7256.4
8	121.8	104.0	0.0	2131.6	6878.7	7256.4
9	121.8	104.0	0.0	2131.6	6878.7	7256.4
10	121.8	104.0	0.0	2131.6	6878.7	7256.4
11	121.8	0.0	0.0	2131.6	0.0	0.0
12	121.8	0.0	0.0	2131.6	0.0	0.0
13	121.8	0.0	0.0	2131.6	0.0	0.0
14	121.8	0.0	0.0	2131.6	0.0	0.0
15	121.8	0.0	0.0	2131.6	0.0	0.0
16	121.8	0.0	0.0	2131.6	0.0	0.0
17	121.8	0.0	0.0	2131.6	0.0	0.0
18	121.8	0.0	0.0	2131.6	0.0	0.0
19	121.8	0.0	0.0	2131.6	0.0	0.0
20	121.8	0.0	0.0	2131.6	0.0	0.0
21	121.8	0.0	0.0	2131.6	0.0	0.0
22	121.8	0.0	0.0	2131.6	0.0	0.0
23	121.8	0.0	0.0	2131.6	0.0	0.0
24	121.8	0.0	0.0	2131.6	0.0	0.0
25	121.8	0.0	0.0	2131.6	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	153.3	156.0	860.5	6399.2	3507.6	6623.4
1	0.0	0.0	0.0	0.0	2676.1	0.0
2	0.0	0.0	0.0	0.0	1884.2	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	0.0	0.0	0.0	0.0	0.0	0.0
Equi.	0.0	1.2	2.0	110.0	0.0	0.0
Criteria						
IRR	79.5	66.3	109.7	33.3	107.8	85.6
ROI	19.9	6.7	6.7	8.3	8.2	11.3
CPM	9999.0	130.0	430.3	58.2	9999.0	9999.0
NPV	0.952	0.483	3.299	12.949	32.233	38.546
EPI	7.2	4.1	4.8	3.0	5.3	6.8

Project:	85	86	87	88	89	90
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	246.2	166.1	296.5	564.2	601.5	73.0
2	238.9	164.9	296.5	564.2	601.5	73.0
3	243.4	164.9	296.5	564.2	601.5	73.0
4	255.9	164.9	296.5	564.2	601.5	73.0
5	255.9	164.9	296.5	564.2	601.5	73.0
6	255.9	164.9	296.5	564.2	601.5	73.0
7	255.9	164.9	296.5	564.2	601.5	73.0
8	255.9	164.9	296.5	564.2	601.5	73.0
9	0.0	0.0	296.5	0.0	601.5	73.0
10	0.0	0.0	296.5	0.0	601.5	73.0
11	0.0	0.0	296.5	0.0	0.0	73.0
12	0.0	0.0	296.5	0.0	0.0	73.0
13	0.0	0.0	296.5	0.0	0.0	73.0
14	0.0	0.0	296.5	0.0	0.0	73.0
15	0.0	0.0	296.5	0.0	0.0	73.0
16	0.0	0.0	296.5	0.0	0.0	73.0
17	0.0	0.0	296.5	0.0	0.0	73.0
18	0.0	0.0	296.5	0.0	0.0	73.0
19	0.0	0.0	296.5	0.0	0.0	73.0
20	0.0	0.0	296.5	0.0	0.0	73.0
21	0.0	0.0	296.5	0.0	0.0	73.0
22	0.0	0.0	296.5	0.0	0.0	73.0
23	0.0	0.0	296.5	0.0	0.0	73.0
24	0.0	0.0	296.5	0.0	0.0	73.0
25	0.0	0.0	296.5	0.0	0.0	73.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	206.0	208.8	618.8	830.3	1023.7	215.4
1	158.0	0.0	0.0	113.7	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	0.0	0.0	0.0	0.0	0.0	0.0
Equi.	2.3	1.1	2.0	12.7	11.4	2.7
Criteria						
IRR	83.4	78.5	47.9	61.3	58.2	33.9
ROI	5.5	6.3	12.0	4.8	5.9	8.5
CPM	158.3	189.8	309.4	74.3	89.9	79.8
NPV	0.983	0.672	2.073	2.076	2.672	0.447
EPI	3.8	4.2	4.4	3.2	3.6	3.1

TABLE 18 (Continued)

Project:	91	92	93	94	95	96
Yr	**Savings (thousands of dollars)**					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	2566.1	207.4	100.9	7439.0	280.3	434.8
2	2566.1	207.4	100.9	1869.0	255.6	434.8
3	2566.1	207.4	100.9	1869.0	255.6	434.8
4	2566.1	207.4	100.9	1869.0	255.6	434.8
5	2566.1	207.4	100.9	1869.0	255.6	434.8
6	2566.1	207.4	100.9	1869.0	0.0	0.0
7	2566.1	207.4	100.9	1869.0	0.0	0.0
8	2566.1	207.4	100.9	1869.0	0.0	0.0
9	2566.1	0.0	100.9	1869.0	0.0	0.0
10	2566.1	0.0	100.9	1869.0	0.0	0.0
11	0.0	0.0	0.0	1869.0	0.0	0.0
12	0.0	0.0	0.0	1869.0	0.0	0.0
13	0.0	0.0	0.0	1869.0	0.0	0.0
14	0.0	0.0	0.0	1869.0	0.0	0.0
15	0.0	0.0	0.0	1869.0	0.0	0.0
16	0.0	0.0	0.0	1869.0	0.0	0.0
17	0.0	0.0	0.0	1869.0	0.0	0.0
18	0.0	0.0	0.0	1869.0	0.0	0.0
19	0.0	0.0	0.0	1869.0	0.0	0.0
20	0.0	0.0	0.0	1869.0	0.0	0.0
21	0.0	0.0	0.0	1869.0	0.0	0.0
22	0.0	0.0	0.0	1869.0	0.0	0.0
23	0.0	0.0	0.0	1869.0	0.0	0.0
24	0.0	0.0	0.0	1869.0	0.0	0.0
25	0.0	0.0	0.0	1869.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	**Costs (thousands of dollars)**					
0	2956.4	349.3	117.0	5451.0	423.4	661.5
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	0.0	0.0	0.0	0.0	13.0	14.0
Equi.	0.0	5.0	0.0	0.0	0.0	0.0
Criteria						
IRR	86.6	57.8	86.1	79.6	55.9	59.3
ROI	8.7	4.8	8.6	9.6	3.1	3.3
CPM	9999.0	69.9	9999.0	9999.0	32.6	47.3
NPV	12.811	0.757	0.503	16.578	0.568	0.987
EPI	5.3	3.2	5.3	4.0	2.3	2.5

Project:	97	98	99	100	101	102
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	797.7	510.0	115.8	90.0	88.9	112.0
2	835.3	510.0	94.5	90.0	88.9	112.0
3	876.4	510.0	94.5	90.0	88.9	112.0
4	921.7	510.0	94.5	90.0	88.9	112.0
5	921.7	510.0	94.5	90.0	88.9	112.0
6	921.7	510.0	0.0	90.0	88.9	112.0
7	921.7	510.0	0.0	90.0	88.9	0.0
8	921.7	510.0	0.0	90.0	88.9	0.0
9	0.0	510.0	0.0	90.0	0.0	0.0
10	0.0	510.0	0.0	90.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	1500.0	850.0	161.8	173.6	136.5	200.0
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	3.0	0.0	4.0	0.0	0.0	0.0
Equi.	15.0	5.3	0.0	2.0	0.8	4.5
Criteria						
IRR	54.9	59.4	57.1	51.0	63.9	51.3
ROI	4.8	6.0	3.1	5.2	5.2	3.4
CPM	83.3	160.4	40.5	86.8	170.6	44.4
NPV	3.199	2.284	0.216	0.379	0.338	0.288
EPI	3.1	3.7	2.3	3.2	3.5	2.4

Project:	103	104	105	106	107	108
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	263.8	430.1	248.7	54.5	465.4	279.6
2	261.3	423.5	248.7	54.5	465.4	270.0
3	261.3	423.5	248.7	54.5	465.4	270.0
4	261.3	417.0	248.7	54.5	465.4	270.0
5	261.3	417.0	248.7	54.5	465.4	270.0
6	261.3	417.0	248.7	54.5	465.4	270.0
7	261.3	417.0	248.7	0.0	465.4	270.0
8	261.3	417.0	248.7	0.0	465.4	270.0
9	261.3	417.0	248.7	0.0	465.4	0.0
10	261.3	417.0	248.7	0.0	465.4	0.0
11	0.0	417.0	248.7	0.0	465.4	0.0
12	0.0	417.0	248.7	0.0	465.4	0.0
13	0.0	417.0	248.7	0.0	465.4	0.0
14	0.0	417.0	248.7	0.0	465.4	0.0
15	0.0	417.0	248.7	0.0	465.4	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	414.3	840.0	681.8	103.9	1411.0	565.3
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	0.0	0.0	8.0	0.0	0.0	8.0
Equi.	0.8	2.0	0.0	1.9	22.7	0.0
Criteria						
IRR	62.8	50.3	36.1	47.3	32.5	46.0
ROI	6.3	7.5	5.5	3.2	5.0	3.8
CPM	517.9	420.0	85.2	54.7	62.2	70.7
NPV	1.194	2.354	1.210	0.134	2.129	0.884
EPI	3.9	3.8	2.8	2.3	2.5	2.6

Project:	109	110	111	112	113	114
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	279.6	182.1	660.0	237.0	181.0	678.6
2	270.0	170.1	660.0	235.0	181.0	678.6
3	270.0	724.0	660.0	239.3	181.0	678.6
4	270.0	174.0	660.0	253.3	181.0	678.6
5	270.0	174.0	660.0	253.3	181.0	678.6
6	270.0	174.0	660.0	253.3	181.0	678.6
7	270.0	174.0	660.0	253.3	181.0	678.6
8	270.0	174.0	660.0	253.3	181.0	678.6
9	0.0	0.0	660.0	0.0	181.0	678.6
10	0.0	0.0	660.0	0.0	0.0	678.6
11	0.0	0.0	0.0	0.0	0.0	678.6
12	0.0	0.0	0.0	0.0	0.0	678.6
13	0.0	0.0	0.0	0.0	0.0	678.6
14	0.0	0.0	0.0	0.0	0.0	678.6
15	0.0	0.0	0.0	0.0	0.0	678.6
16	0.0	0.0	0.0	0.0	0.0	678.6
17	0.0	0.0	0.0	0.0	0.0	678.6
18	0.0	0.0	0.0	0.0	0.0	678.6
19	0.0	0.0	0.0	0.0	0.0	678.6
20	0.0	0.0	0.0	0.0	0.0	678.6
21	0.0	0.0	0.0	0.0	0.0	678.6
22	0.0	0.0	0.0	0.0	0.0	678.6
23	0.0	0.0	0.0	0.0	0.0	678.6
24	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	565.3	459.6	930.0	363.6	361.9	1419.1
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	8.0	0.0	0.0	0.0	0.0	0.0
Equi.	0.0	3.7	0.0	0.8	3.3	0.0
Criteria						
IRR	46.0	54.8	70.6	64.9	48.6	47.8
ROI	3.8	4.2	7.1	5.4	4.5	11.0
CPM	70.7	124.2	9999.0	454.5	109.7	9999.0
NPV	0.884	0.886	3.125	0.947	0.681	4.609
EPI	2.6	2.9	4.4	3.6	2.9	4.3

Project:	115	116	117	118	119	120
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	123.0	0.0	0.0
1	165.0	92.1	141.8	123.0	66.5	463.6
2	173.0	94.4	141.8	123.0	66.5	425.7
3	154.0	94.4	141.8	123.0	66.5	425.7
4	154.0	111.5	141.8	123.0	66.5	425.7
5	116.0	111.5	141.8	123.0	66.5	425.7
6	0.0	111.5	141.8	123.0	0.0	425.7
7	0.0	111.5	141.8	123.0	0.0	425.7
8	0.0	111.5	141.8	0.0	0.0	425.7
9	0.0	0.0	141.8	0.0	0.0	0.0
10	0.0	0.0	141.8	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	162.0	170.2	273.0	240.0	137.0	740.5
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	0.0	0.0	0.0	0.0	5.0	0.0
Equi.	0.0	0.8	1.3	0.0	0.0	2.7
Criteria						
IRR	97.4	55.7	51.1	104.4	39.3	57.9
ROI	4.7	4.9	5.2	4.1	2.4	4.7
CPM	9999.0	212.8	210.0	9999.0	27.4	274.3
NPV	0.424	0.380	0.598	0.482	0.115	1.565
EPI	3.6	3.2	3.2	3.0	1.8	3.1

Project:	121	122	123	124	125	126
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	170.6	191.0	125.0	96.4	185.1	182.6
2	170.6	202.5	125.0	76.8	176.0	182.6
3	170.6	222.8	125.0	76.8	167.8	182.6
4	170.6	240.6	125.0	76.8	156.6	182.6
5	170.6	240.6	125.0	76.8	156.6	182.6
6	170.6	240.6	125.0	76.8	156.6	182.6
7	170.6	240.6	125.0	76.8	156.6	182.6
8	170.6	240.6	125.0	76.8	156.6	182.6
9	0.0	240.6	125.0	76.8	0.0	182.6
10	0.0	240.6	125.0	76.8	0.0	182.6
11	0.0	240.6	125.0	0.0	0.0	0.0
12	0.0	240.6	125.0	0.0	0.0	0.0
13	0.0	240.6	125.0	0.0	0.0	0.0
14	0.0	240.6	125.0	0.0	0.0	0.0
15	0.0	240.6	125.0	0.0	0.0	0.0
16	0.0	0.0	125.0	0.0	0.0	0.0
17	0.0	0.0	125.0	0.0	0.0	0.0
18	0.0	0.0	125.0	0.0	0.0	0.0
19	0.0	0.0	125.0	0.0	0.0	0.0
20	0.0	0.0	125.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	227.5	550.0	267.5	175.9	284.4	290.8
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	0.0	0.0	0.0	0.0	0.0	0.0
Equi.	0.0	2.0	0.0	1.2	0.8	0.0
Criteria						
IRR	74.1	39.0	46.7	46.2	59.7	62.3
ROI	6.0	6.4	9.3	4.5	4.6	6.3
CPM	9999.0	275.0	9999.0	146.6	355.5	9999.0
NPV	0.683	1.190	0.797	0.314	0.601	0.831
EPI	4.0	3.2	4.0	2.8	3.1	3.9

Project:	127	128	129	130	131	132
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	65.7	340.8	237.5	40.9	0.0	69.9
2	54.0	340.8	237.5	40.9	5458.6	69.9
3	54.0	340.8	237.5	40.9	0.0	69.9
4	54.0	340.8	237.5	40.9	5458.6	69.9
5	54.0	340.8	237.5	40.9	0.0	69.9
6	54.0	340.8	237.5	40.9	5458.6	69.9
7	54.0	340.8	237.5	40.9	0.0	69.9
8	54.0	340.8	237.5	40.9	5458.6	69.9
9	0.0	340.8	0.0	40.9	0.0	0.0
10	0.0	340.8	0.0	40.9	5458.6	0.0
11	0.0	0.0	0.0	40.9	0.0	0.0
12	0.0	0.0	0.0	40.9	5458.6	0.0
13	0.0	0.0	0.0	40.9	0.0	0.0
14	0.0	0.0	0.0	40.9	5458.6	0.0
15	0.0	0.0	0.0	40.9	0.0	0.0
16	0.0	0.0	0.0	40.9	5458.6	0.0
17	0.0	0.0	0.0	40.9	0.0	0.0
18	0.0	0.0	0.0	40.9	0.0	0.0
19	0.0	0.0	0.0	40.9	0.0	0.0
20	0.0	0.0	0.0	40.9	0.0	0.0
21	0.0	0.0	0.0	40.9	0.0	0.0
22	0.0	0.0	0.0	40.9	0.0	0.0
23	0.0	0.0	0.0	40.9	0.0	0.0
24	0.0	0.0	0.0	40.9	0.0	0.0
25	0.0	0.0	0.0	40.9	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	132.0	549.4	505.0	255.0	5000.0	154.6
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	0.0	0.0	0.0	6.0	0.0	0.0
Equi.	1.5	0.0	3.9	1.4	0.0	1.3
Criteria						
IRR	40.8	61.5	44.6	15.6	44.5	42.6
ROI	3.4	6.2	3.8	4.0	8.7	3.6
CPM	88.0	9999.0	129.5	34.5	9999.0	118.9
NPV	0.167	1.545	0.762	0.116	15.336	0.218
EPI	2.3	3.8	2.5	1.5	4.1	2.4

Project:	133	134	135	136	137	138
Yr	**Savings (thousands of dollars)**					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	252.2	697.1	94.8	0.0	1338.6	37.6
2	252.2	610.1	84.3	0.0	1338.6	41.4
3	252.2	610.1	84.3	1401.7	1338.6	45.5
4	252.2	610.1	84.3	1401.7	1338.6	50.0
5	252.2	610.1	84.3	1401.7	1338.6	50.0
6	252.2	610.1	84.3	1401.7	1338.6	50.0
7	252.2	610.1	84.3	1401.7	1338.6	50.0
8	252.2	610.1	84.3	1401.7	1338.6	50.0
9	252.2	610.1	84.3	1401.7	1338.6	0.0
10	252.2	610.1	84.3	1401.7	1338.6	0.0
11	252.2	610.1	0.0	1401.7	1338.6	0.0
12	252.2	610.1	0.0	1401.7	1338.6	0.0
13	252.2	610.1	0.0	1401.7	1338.6	0.0
14	252.2	610.1	0.0	1401.7	1338.6	0.0
15	252.2	610.1	0.0	1401.7	1338.6	0.0
16	252.2	610.1	0.0	1401.7	1338.6	0.0
17	252.2	610.1	0.0	1401.7	1338.6	0.0
18	252.2	610.1	0.0	1401.7	1338.6	0.0
19	252.2	610.1	0.0	1401.7	1338.6	0.0
20	252.2	610.1	0.0	1401.7	1338.6	0.0
21	252.2	610.1	0.0	1401.7	1338.6	0.0
22	252.2	610.1	0.0	1401.7	1338.6	0.0
23	252.2	610.1	0.0	1401.7	1338.6	0.0
24	252.2	610.1	0.0	1401.7	1338.6	0.0
25	252.2	610.1	0.0	1401.7	1338.6	0.0
26	0.0	0.0	0.0	1401.7	0.0	0.0
27	0.0	0.0	0.0	1401.7	0.0	0.0
Yr	**Costs (thousands of dollars)**					
0	670.8	1966.3	192.3	4684.8	3790.5	137.6
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	0.0	0.0	0.0	14.0	0.0	0.0
Equi.	0.0	3.1	1.0	0.0	0.0	2.2
Criteria						
IRR	37.6	32.1	44.4	20.4	35.3	27.8
ROI	9.4	7.8	4.4	7.5	8.8	2.7
CPM	9999.0	634.3	192.3	334.6	9999.0	62.5
NPV	1.618	3.651	0.335	5.830	8.360	0.107
EPI	3.4	2.9	2.7	2.[illegible]	3.2	1.8

TABLE 18 (Continued)

Project:	139	140	141	142	143	144
Yr	**Savings (thousands of dollars)**					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	183.3	103.0	192.0	156.5	353.2	205.6
2	183.3	107.7	199.7	156.5	353.2	181.8
3	183.3	112.6	207.7	156.5	353.2	181.8
4	183.3	117.7	216.7	156.5	353.2	180.6
5	183.3	128.8	216.7	156.5	353.2	180.6
6	183.3	128.8	216.7	156.5	353.2	180.6
7	183.3	128.8	216.7	156.5	353.2	180.6
8	183.3	0.0	216.7	156.5	353.2	180.6
9	183.3	0.0	216.7	156.5	0.0	180.6
10	183.3	0.0	216.7	156.5	0.0	180.6
11	183.3	0.0	216.7	156.5	0.0	180.6
12	183.3	0.0	216.7	156.5	0.0	180.6
13	183.3	0.0	216.7	156.5	0.0	180.6
14	183.3	0.0	216.7	156.5	0.0	180.6
15	183.3	0.0	216.7	156.5	0.0	130.6
16	183.3	0.0	216.7	156.5	0.0	0.0
17	183.3	0.0	216.7	156.5	0.0	0.0
18	183.3	0.0	216.7	156.5	0.0	0.0
19	183.3	0.0	216.7	156.5	0.0	0.0
20	183.3	0.0	216.7	156.5	0.0	0.0
21	183.3	0.0	216.7	156.5	0.0	0.0
22	183.3	0.0	216.7	156.5	0.0	0.0
23	183.3	0.0	216.7	156.5	0.0	0.0
24	183.3	0.0	216.7	156.5	0.0	0.0
25	183.3	0.0	216.7	156.5	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	**Costs (thousands of dollars)**					
0	702.1	203.1	800.0	457.8	1038.4	560.0
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	0.0	0.0	0.0	0.0	0.0	0.0
Equi.	1.6	0.2	1.3	0.0	12.6	1.5
Criteria						
IRR	26.0	51.6	25.9	34.2	29.8	33.0
ROI	6.5	4.1	6.7	8.6	2.7	4.9
CPM	438.8	1015.5	615.4	9999.0	82.4	373.3
NPV	0.962	0.363	1.124	0.963	0.846	0.838
EPI	2.4	2.8	2.4	3.1	1.8	2.5

Project:	145	146	147	148	149	150
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	613.1	314.1	0.0	3418.9	0.0	175.0
2	249.1	314.1	4437.1	3418.9	1522.0	340.0
3	249.1	314.1	4437.1	3418.9	1543.6	430.0
4	249.1	314.1	4437.1	3418.9	1566.2	430.0
5	249.1	314.1	4437.1	3418.9	1590.0	430.0
6	249.1	314.1	4437.1	3418.9	1615.0	430.0
7	249.1	314.1	4437.1	3418.9	1641.3	430.0
8	249.1	314.1	4437.1	3418.9	1688.9	430.0
9	249.1	314.1	4437.1	3418.9	1697.8	0.0
10	249.1	314.1	0.0	3418.9	0.0	0.0
11	249.1	0.0	0.0	3418.9	0.0	0.0
12	249.1	0.0	0.0	3418.9	0.0	0.0
13	249.1	0.0	0.0	3418.9	0.0	0.0
14	249.1	0.0	0.0	3418.9	0.0	0.0
15	249.1	0.0	0.0	3418.9	0.0	0.0
16	249.1	0.0	0.0	3418.9	0.0	0.0
17	249.1	0.0	0.0	3418.9	0.0	0.0
18	249.1	0.0	0.0	3418.9	0.0	0.0
19	249.1	0.0	0.0	3418.9	0.0	0.0
20	249.1	0.0	0.0	3418.9	0.0	0.0
21	249.1	0.0	0.0	3418.9	0.0	0.0
22	249.1	0.0	0.0	3418.9	0.0	0.0
23	249.1	0.0	0.0	3418.9	0.0	0.0
24	249.1	0.0	0.0	3418.9	0.0	0.0
25	249.1	0.0	0.0	3418.9	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	1350.0	651.2	837.0	11050.0	648.2	1150.0
1	0.0	0.0	3651.0	0.0	3208.8	0.0
2	0.0	0.0	4536.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	7.0	0.0	0.0	0.0	0.0	0.0
Equi.	0.0	0.0	0.0	0.0	13.5	12.0
Criteria						
IRR	23.5	47.2	54.6	30.9	35.0	25.6
ROI	4.9	4.8	3.9	7.7	3.3	2.7
CPM	192.9	9999.0	9999.0	9999.0	285.7	95.8
NPV	1.242	1.279	13.615	19.984	4.171	0.838
EPI	1.9	3.0	2.7	2.8	2.2	1.7

Project:	151	152	153	154	155	156
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	84.8	104.1	258.4	86.2	237.1
2	173.8	84.8	110.5	258.4	77.8	0.0
3	173.8	84.8	117.3	258.4	77.8	220.9
4	173.8	84.8	124.5	258.4	77.8	0.0
5	173.8	84.8	124.5	258.4	77.8	220.9
6	173.8	0.0	124.5	258.4	0.0	0.0
7	173.8	0.0	124.5	258.4	0.0	220.9
8	173.8	0.0	124.5	258.4	0.0	0.0
9	173.8	0.0	124.5	258.4	0.0	0.0
10	173.8	0.0	124.5	258.4	0.0	0.0
11	173.8	0.0	124.5	0.0	0.0	0.0
12	0.0	0.0	124.5	0.0	0.0	0.0
13	0.0	0.0	124.5	0.0	0.0	0.0
14	0.0	0.0	124.5	0.0	0.0	0.0
15	0.0	0.0	124.5	0.0	0.0	0.0
16	0.0	0.0	124.5	0.0	0.0	0.0
17	0.0	0.0	124.5	0.0	0.0	0.0
18	0.0	0.0	124.5	0.0	0.0	0.0
19	0.0	0.0	124.5	0.0	0.0	0.0
20	0.0	0.0	124.5	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	312.5	163.0	362.0	693.7	290.2	311.8
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	0.0	0.0	0.0	1.0	4.0	0.0
Equi.	0.0	0.5	0.0	0.0	0.0	0.4
Criteria						
IRR	38.6	43.5	31.9	35.5	11.7	40.0
ROI	5.6	2.6	6.8	3.7	1.4	2.9
CPM	9999.0	326.0	9999.0	693.7	72.6	779.5
NPV	0.658	0.159	0.662	0.894	0.012	0.320
EPI	3.1	2.0	2.8	2.3	1.0	2.0

Project:	157	158	159	160	161	162
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	89.7	62.3	0.0	45.8	230.4	120.4
2	96.6	60.9	300.0	45.8	230.4	146.1
3	104.0	60.9	300.0	45.8	230.4	162.3
4	112.0	60.9	300.0	45.8	230.4	179.1
5	112.0	60.9	300.0	45.8	230.4	179.1
6	112.0	60.9	300.0	45.8	230.4	179.1
7	112.0	60.9	300.0	45.8	230.4	179.1
8	112.0	60.9	300.0	45.8	230.4	179.1
9	112.0	0.0	300.0	0.0	230.4	0.0
10	112.0	0.0	300.0	0.0	230.4	0.0
11	112.0	0.0	300.0	0.0	0.0	0.0
12	112.0	0.0	0.0	0.0	0.0	0.0
13	112.0	0.0	0.0	0.0	0.0	0.0
14	112.0	0.0	0.0	0.0	0.0	0.0
15	112.0	0.0	0.0	0.0	0.0	0.0
16	112.0	0.0	0.0	0.0	0.0	0.0
17	112.0	0.0	0.0	0.0	0.0	0.0
18	112.0	0.0	0.0	0.0	0.0	0.0
19	112.0	0.0	0.0	0.0	0.0	0.0
20	112.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	344.3	199.7	893.0	180.5	735.0	714.0
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	0.0	0.0	0.0	0.0	0.0	4.0
Equi.	0.0	1.3	3.0	2.0	1.7	3.0
Criteria						
IRR	29.8	25.8	23.9	19.1	28.9	15.1
ROI	6.4	2.5	3.4	2.0	3.1	1.9
CPM	9999.0	153.6	297.7	90.3	432.4	102.0
NPV	0.570	0.127	0.783	0.064	0.681	0.148
EPI	2.7	1.6	1.9	1.4	1.9	1.2

TABLE 18 (Continued)

Project:	163	164	165	166	167	168
Yr	**Savings (thousands of dollars)**					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	266.2	181.0	420.9	152.0	0.0	0.0
2	278.7	181.0	415.9	152.0	0.0	255.3
3	292.5	181.0	415.9	152.0	530.0	255.3
4	307.6	181.0	415.9	152.0	570.0	255.3
5	307.6	181.0	415.9	152.0	610.0	255.3
6	307.6	181.0	415.9	152.0	650.0	255.3
7	307.6	181.0	415.9	152.0	690.0	255.3
8	307.6	181.0	415.9	152.0	730.0	255.3
9	0.0	0.0	415.9	152.0	770.0	255.3
10	0.0	0.0	415.9	152.0	770.0	255.3
11	0.0	0.0	0.0	0.0	770.0	255.3
12	0.0	0.0	0.0	0.0	0.0	255.3
13	0.0	0.0	0.0	0.0	0.0	255.3
14	0.0	0.0	0.0	0.0	0.0	255.3
15	0.0	0.0	0.0	0.0	0.0	255.3
16	0.0	0.0	0.0	0.0	0.0	255.3
17	0.0	0.0	0.0	0.0	0.0	255.3
18	0.0	0.0	0.0	0.0	0.0	255.3
19	0.0	0.0	0.0	0.0	0.0	255.3
20	0.0	0.0	0.0	0.0	0.0	255.3
21	0.0	0.0	0.0	0.0	0.0	255.3
22	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	**Costs (thousands of dollars)**					
0	660.0	563.0	992.5	400.0	1500.0	845.0
1	0.0	0.0	114.8	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	600.0	0.0
3	0.0	0.0	0.0	0.0	100.0	0.0
Labor savings (manpower positions)						
Auth.	0.0	0.0	0.0	0.0	5.0	0.0
Equi.	0.0	1.8	0.0	0.0	4.0	0.0
Criteria						
IRR	40.5	27.6	37.1	36.3	17.9	24.0
ROI	3.6	2.6	3.8	3.8	2.8	6.0
CPM	9999.0	312.8	9999.0	9999.0	244.4	9999.0
NPV	0.908	0.403	1.463	0.534	1.050	1.131
EPI	2.4	1.7	2.3	2.3	1.5	2.3

Project:	169	170	171	172	173	174
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	45.0	126.6	175.9	0.0	115.0	0.0
2	45.0	107.0	171.3	115.0	115.0	425.2
3	45.0	107.0	170.2	115.0	115.0	425.2
4	45.0	107.0	170.2	115.0	115.0	425.2
5	45.0	107.0	170.2	115.0	115.0	425.2
6	45.0	107.0	170.2	115.0	115.0	425.2
7	45.0	107.0	170.2	115.0	115.0	425.2
8	45.0	107.0	170.2	115.0	115.0	425.2
9	45.0	107.0	170.2	115.0	115.0	425.2
10	45.0	107.0	170.2	115.0	115.0	425.2
11	0.0	0.0	0.0	115.0	0.0	425.2
12	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	120.0	475.0	624.2	263.3	315.5	1345.0
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	0.0	0.0	0.0	0.0	0.0	0.0
Equi.	0.0	2.5	1.4	0.0	0.0	1.4
Criteria						
IRR	35.7	19.4	24.4	31.1	34.6	22.4
ROI	3.8	2.3	2.7	4.4	3.7	3.2
CPM	9999.0	190.0	445.9	9999.0	9999.0	960.7
NPV	0.157	0.200	0.428	0.379	0.391	1.030
EPI	2.3	1.4	1.7	2.4	2.2	1.8

Project:	175	176	177	178	179	180
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	53.9	0.0	0.0
1	2563.0	0.0	69.4	193.8	61.2	0.0
2	613.0	100.7	72.0	193.8	61.2	53.7
3	613.0	100.7	69.4	193.8	61.2	53.7
4	613.0	100.7	65.6	193.8	61.2	53.7
5	613.0	100.7	65.6	96.9	61.2	53.7
6	613.0	100.7	65.6	0.0	61.2	53.7
7	613.0	100.7	65.6	0.0	61.2	53.7
8	613.0	100.7	65.6	0.0	61.2	53.7
9	613.0	100.7	0.0	0.0	61.2	53.7
10	613.0	100.7	0.0	0.0	61.2	53.7
11	613.0	100.7	0.0	0.0	0.0	53.7
12	613.0	0.0	0.0	0.0	0.0	0.0
13	613.0	0.0	0.0	0.0	0.0	0.0
14	613.0	0.0	0.0	0.0	0.0	0.0
15	613.0	0.0	0.0	0.0	0.0	0.0
16	613.0	0.0	0.0	0.0	0.0	0.0
17	613.0	0.0	0.0	0.0	0.0	0.0
18	613.0	0.0	0.0	0.0	0.0	0.0
19	613.0	0.0	0.0	0.0	0.0	0.0
20	613.0	0.0	0.0	0.0	0.0	0.0
21	613.0	0.0	0.0	0.0	0.0	0.0
22	613.0	0.0	0.0	0.0	0.0	0.0
23	613.0	0.0	0.0	0.0	0.0	0.0
24	613.0	0.0	0.0	0.0	0.0	0.0
25	613.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	3700.0	340.5	183.1	450.0	202.0	161.5
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	0.0	0.0	0.0	0.0	0.0	0.0
Equi.	0.0	0.6	0.0	0.0	0.0	0.0
Criteria						
IRR	28.1	20.8	33.8	36.9	27.7	23.7
ROI	4.7	3.0	2.9	2.1	3.0	3.3
CPM	9999.0	567.5	9999.0	9999.0	9999.0	9999.0
NPV	3.637	0.222	0.179	0.278	0.174	0.139
EPI	2.0	1.7	2.0	1.6	1.9	1.9

Project:	181	182	183	184	185	186
Yr	Savings (thousands of dollars)					
0	0.0	0.0	0.0	0.0	0.0	0.0
1	1671.0	166.3	52.8	2006.7	61.9	0.0
2	1671.0	162.8	52.8	2006.7	61.9	1068.2
3	1443.0	158.8	52.8	2006.7	61.9	463.9
4	1443.0	158.8	52.8	2006.7	61.9	463.9
5	1443.0	158.8	52.8	2006.7	61.9	463.9
6	1443.0	158.8	52.8	2006.7	61.9	463.9
7	1443.0	158.8	52.8	2006.7	61.9	463.9
8	1443.0	158.8	52.8	2006.7	61.9	463.9
9	0.0	158.8	52.8	2006.7	0.0	463.9
10	0.0	0.0	52.8	2006.7	0.0	463.9
11	0.0	0.0	0.0	0.0	0.0	463.9
12	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
Yr	Costs (thousands of dollars)					
0	5011.5	585.0	206.1	7935.4	240.0	2207.4
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
Labor savings (manpower positions)						
Auth.	0.0	0.0	0.0	0.0	0.0	0.0
Equi.	0.0	0.0	0.0	0.0	0.0	0.0
Criteria						
IRR	25.9	23.4	22.2	21.8	19.7	17.9
ROI	2.4	2.5	2.6	2.5	2.1	2.4
CPM	9999.0	9999.0	9999.0	9999.0	9999.0	9999.0
NPV	3.083	0.340	0.118	4.395	0.090	0.883
EPI	1.6	1.6	1.6	1.6	1.4	1.4

TABLE 19

IP AND RANKED SOLUTION MIXES

(BUDGET CEILING = $73.1 MILLION)

		DoD Criteria		Other Criteria				
Project	IP	(as if)	(actual)	IRR	ROI	CPM	NPV	EPI
1	1	1	1	1	1	1	0	1
2	1	1	1	1	1	1	0	1
3	1	1	0	1	1	1	1	1
4	1	1	1	1	1	1	0	1
5	1	1	0	1	1	1	0	1
6	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	0	1
9	1	1	1	1	1	1	0	1
10	1	1	1	1	1	1	0	1
11	1	1	1	1	1	1	1	1
12	1	1	1	1	0	1	0	1
13	1	1	1	1	1	1	0	1
14	1	1	1	1	1	1	0	1
15	1	1	1	1	1	1	0	1
16	1	1	1	1	1	1	0	1
17	0	1	1	1	0	1	0	1
18	0	1	1	1	0	1	0	0
19	1	1	0	0	1	1	0	1
20	0	1	1	1	0	1	0	0
21	0	1	1	1	0	1	0	1
22	1	1	1	0	1	0	1	1
23	1	1	1	1	1	0	0	1
24	0	1	1	1	0	1	0	0
25	0	1	1	0	0	1	0	0
26	0	1	1	1	0	1	0	0
27	1	1	0	0	1	0	0	1
28	0	1	1	1	0	1	0	0
29	0	1	1	1	0	0	0	1
30	1	1	1	1	0	0	0	1
31	0	1	0	1	0	0	0	1
32	0	1	1	1	0	0	0	1
33	1	1	1	1	1	0	0	1
34	1	1	1	1	1	0	0	1
35	1	1	0	1	1	0	0	1
36	1	1	1	1	1	0	0	1
37	1	1	0	0	1	0	1	1
38	0	1	0	0	0	1	0	0
39	1	1	0	1	1	0	0	1

TABLE 19 (Continued)

		DoD Criteria		Other Criteria				
Project	IP	(as if)	(actual)	IRR	ROI	CPM	NPV	EPI
40	1	1	1	1	1	0	0	1
41	0	1	1	0	0	0	0	0
42	1	1	1	1	1	0	0	1
43	1	0	0	1	1	0	1	1
44	0	1	1	0	0	1	0	0
45	1	0	1	1	1	0	0	1
46	0	1	0	0	0	0	0	0
47	1	0	1	1	0	0	0	1
48	0	0	0	0	0	1	0	0
49	0	0	0	1	0	0	0	0
50	0	0	0	0	1	0	0	0
51	0	0	0	0	0	1	0	0
52	0	0	1	0	0	1	0	0
53	0	1	0	0	0	1	0	0
54	0	0	0	0	0	1	0	0
55	0	0	0	0	1	0	0	1
56	0	0	0	1	0	0	0	0
57	0	0	0	1	0	0	0	0
58	0	0	0	0	0	1	0	0
59	0	0	0	0	0	1	0	0
60	0	0	0	0	0	0	1	0
61	0	0	0	1	0	0	0	1
62	0	0	0	1	0	0	0	0
63	0	0	0	1	0	0	0	0
64	0	0	0	0	0	0	0	0
65	0	0	0	0	0	1	0	0
66	0	0	1	1	0	0	0	0
67	0	0	0	0	0	0	0	0
68	0	0	0	0	0	0	0	0
69	1	0	0	0	0	0	1	0
70	0	0	0	0	0	1	0	0
71	0	0	0	0	0	0	0	0
72	0	0	0	0	0	0	0	0
73	0	0	0	0	0	0	0	0
74	0	0	0	0	0	0	0	0
75	0	0	0	0	1	0	0	0
76	0	0	0	1	0	0	0	0
77	0	0	0	0	0	1	0	0
78	0	0	0	0	0	1	0	0
79	0	0	1	0	1	0	0	1
80	0	0	0	0	0	0	0	0
81	0	0	0	1	0	0	0	0
82	0	0	0	0	0	1	0	0
83	1	0	1	1	0	0	0	0
84	0	0	0	0	0	0	1	0
85	0	0	0	0	0	0	0	0

TABLE 19 (Continued)

		DoD Criteria		Other Criteria				
Project	IP	(as if)	(actual)	IRR	ROI	CPM	NPV	EPI
86	0	0	0	0	0	0	0	0
87	0	0	0	0	0	0	0	0
88	0	0	0	0	0	1	0	0
89	0	0	0	0	0	0	0	0
90	0	0	0	0	0	1	0	0
91	0	0	0	0	0	0	0	0
92	0	0	0	0	0	1	0	0
93	0	0	0	0	0	0	0	0
94	0	0	0	0	0	0	0	0
95	0	0	0	0	0	1	0	0
96	0	0	0	0	0	1	0	0
97	0	0	0	0	0	0	0	0
98	0	0	0	0	0	0	0	0
99	0	0	0	0	0	1	0	0
100	0	0	0	0	0	1	0	0
101	0	0	0	0	0	0	0	0
102	0	0	0	0	0	1	0	0
103	0	0	0	0	0	0	0	0
104	0	0	0	0	0	0	0	0
105	0	0	1	0	0	0	0	0
106	0	0	0	0	0	1	0	0
107	0	0	0	0	0	1	0	0
108	0	0	0	0	0	1	0	0
109	0	0	0	0	0	1	0	0
110	0	0	0	0	0	0	0	0
111	0	0	0	0	0	0	0	0
112	0	0	0	0	0	0	0	0
113	0	0	0	0	0	0	0	0
114	0	0	0	0	0	0	0	0
115	0	0	0	1	0	0	0	0
116	0	0	0	0	0	0	0	0
117	0	0	0	0	0	0	0	0
118	0	0	0	1	0	0	0	0
119	0	0	0	0	0	1	0	0
120	0	0	0	0	0	0	0	0
121	0	0	0	0	0	0	0	0
122	0	0	0	0	0	0	0	0
123	0	0	0	0	0	0	0	0
124	0	0	0	0	0	0	0	0
125	0	0	0	0	0	0	0	0
126	0	0	0	0	0	0	0	0
127	0	0	0	0	0	0	0	0
128	0	0	0	0	0	0	0	0
129	0	0	0	0	0	0	0	0
130	0	0	0	0	0	1	0	0
131	0	0	0	0	0	0	0	0

TABLE 19 (Continued)

		DoD Criteria		Other Criteria				
Project	IP	(as if)	(actual)	IRR	ROI	CPM	NPV	EPI
132	0	0	0	0	0	0	0	0
133	0	0	0	0	0	0	0	0
134	0	0	0	0	0	0	0	0
135	0	0	0	0	0	0	0	0
136	0	0	0	0	0	0	0	0
137	0	0	0	0	0	0	0	0
138	0	0	0	0	0	1	0	0
139	0	0	0	0	0	0	0	0
140	0	0	0	0	0	0	0	0
141	0	0	0	0	0	0	0	0
142	0	0	0	0	0	0	0	0
143	0	0	0	0	0	0	0	0
144	0	0	0	0	0	0	0	0
145	0	0	0	0	0	0	0	0
146	0	0	0	0	0	0	0	0
147	1	0	0	0	0	0	0	0
148	0	0	0	0	0	0	0	0
149	0	0	0	0	0	0	0	0
150	0	0	0	0	0	0	0	0
151	0	0	0	0	0	0	0	0
152	0	0	0	0	0	0	0	0
153	0	0	0	0	0	0	0	0
155	0	0	0	0	0	1	0	0
156	0	0	0	0	0	0	0	0
157	0	0	0	0	0	0	0	0
158	0	0	0	0	0	0	0	0
159	0	0	0	0	0	0	0	0
160	0	0	0	0	0	0	0	0
161	0	0	0	0	0	0	0	0
162	0	0	0	0	0	0	0	0
163	0	0	0	0	0	0	0	0
164	0	0	0	0	0	0	0	0
165	0	0	0	0	0	0	0	0
166	0	0	0	0	0	0	0	0
167	0	0	0	0	0	0	0	0
168	0	0	0	0	0	0	0	0
169	0	0	0	0	0	0	0	0
170	0	0	0	0	0	0	0	0
171	0	0	0	0	0	0	0	0
172	0	0	0	0	0	0	0	0
173	0	0	0	0	0	0	0	0
174	0	0	0	0	0	0	0	0
175	0	0	0	0	0	0	0	0
176	0	0	0	0	0	0	0	0
177	0	0	0	0	0	0	0	0
178	0	0	0	0	0	0	0	0

TABLE 19 (Continued)

		DoD Criteria		Other Criteria				
Project	IP	(as if)	(actual)	IRR	ROI	CPM	NPV	EPI
179	0	0	0	0	0	0	0	0
180	0	0	0	0	0	0	0	0
181	0	0	0	0	0	0	0	0
182	0	0	0	0	0	0	0	0
183	0	0	0	0	0	0	0	0
184	0	0	0	0	0	0	0	0
185	0	0	0	0	0	0	0	0
186	0	0	0	0	0	0	0	0
Total in Mix	35	45	42	51	33	55	10	40

TABLE 20

IP AND RANKED SOLUTION MIXES

(BUDGET CEILING = $136.4 MILLION)

			Other Criteria				
Project	IP	DoD (as if)	IRR	ROI	CPM	NPV	EPI
1	1	1	1	1	1	1	1
2	1	1	1	1	1	0	1
3	1	1	1	1	1	1	1
4	1	1	1	1	1	0	1
5	1	1	1	1	1	0	1
6	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1
9	1	1	1	1	1	0	1
10	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1
12	1	1	1	1	1	0	1
13	1	1	1	1	1	0	1
14	1	1	1	1	1	0	1
15	1	1	1	1	1	0	1
16	1	1	1	1	1	0	1
17	1	1	1	1	1	0	1
18	1	1	1	1	1	1	1
19	1	1	1	1	1	0	1
20	1	1	1	1	1	0	1
21	1	1	1	1	1	0	1
22	1	1	1	1	1	1	1
23	1	1	1	1	1	0	1
24	1	1	1	0	1	0	1
25	1	1	1	1	1	0	1
26	1	1	1	0	1	0	1
27	1	1	1	1	0	0	1
28	1	1	1	0	1	0	1
29	1	1	1	1	1	0	1
30	1	1	1	1	1	0	1
31	1	1	1	1	1	0	1
32	1	1	1	1	1	0	1
33	1	1	1	1	0	0	1
34	1	1	1	1	0	1	1
35	1	1	1	1	0	0	1
36	1	1	1	1	0	1	1
37	1	1	1	1	1	1	1
38	1	1	0	1	1	0	1
39	1	1	1	1	0	0	1

TABLE 20 (Continued)

Project	IP	DoD (as if)	Other Criteria IRR	ROI	CPM	NPV	EPI
40	1	1	1	1	0	1	1
41	1	1	1	1	1	0	1
42	1	1	1	1	0	0	1
43	1	1	1	1	0	1	1
44	1	1	1	0	1	0	1
45	1	1	1	1	0	1	1
46	1	1	1	1	1	0	1
47	1	1	1	1	0	0	1
48	1	1	0	1	1	0	1
49	1	1	1	0	1	0	1
50	1	1	1	1	1	0	1
51	1	1	0	0	1	0	1
52	0	1	1	0	1	1	0
53	1	1	1	0	1	0	1
54	0	1	0	0	1	0	0
55	1	1	0	1	0	0	1
56	1	1	1	1	0	0	1
57	1	1	1	0	1	0	1
58	0	1	1	0	1	0	0
59	0	1	0	0	0	0	0
60	1	1	1	1	0	1	1
61	1	1	1	1	0	0	1
62	1	1	1	0	1	0	1
63	1	1	1	0	1	0	1
64	1	1	1	1	1	0	1
65	0	1	0	0	1	0	0
66	0	1	1	0	0	0	0
67	0	1	0	1	1	0	0
68	0	1	1	1	1	0	1
69	1	1	1	1	0	1	1
70	0	1	0	1	1	0	0
71	1	1	1	0	1	0	1
72	1	1	1	1	0	0	1
73	0	0	0	0	1	1	0
74	0	1	1	0	1	0	1
75	1	0	0	1	0	1	1
76	1	1	1	0	0	0	1
77	0	1	0	0	1	0	0
78	0	1	0	0	1	0	0
79	1	1	1	1	0	0	1
80	0	1	0	1	1	0	1
81	1	1	1	0	0	0	1
82	0	0	0	0	1	0	0
83	1	0	1	0	0	1	1
84	1	0	1	1	0	1	1
85	1	1	1	0	1	0	0

TABLE 20 (Continued)

Project	IP	DoD (as if)	Other Criteria IRR	ROI	CPM	NPV	EPI
86	0	1	1	0	0	0	1
87	0	1	0	1	0	0	0
88	0	1	0	0	1	0	0
89	0	0	0	0	1	0	0
90	0	1	0	1	1	0	0
91	1	0	1	1	0	0	1
92	0	1	0	0	1	0	0
93	1	0	1	1	0	0	1
94	0	0	0	1	0	1	0
95	0	0	0	0	1	0	0
96	0	0	0	0	1	0	0
97	0	0	0	0	1	0	0
98	0	0	0	0	1	0	0
99	0	0	0	0	1	0	0
100	0	0	0	0	1	0	0
101	0	0	0	0	1	0	0
102	0	0	0	0	1	0	0
103	0	0	0	0	0	0	0
104	0	0	0	0	0	0	0
105	0	0	0	0	1	0	0
106	0	0	0	0	1	0	0
107	0	0	0	0	1	0	0
108	0	0	0	0	1	0	0
109	0	0	0	0	1	0	0
110	0	0	0	0	1	0	0
111	0	0	0	0	0	0	1
112	0	0	0	0	0	0	0
113	0	0	0	0	1	0	0
114	0	0	0	1	0	0	0
115	0	0	1	0	0	0	0
116	0	0	0	0	0	0	0
117	0	0	0	0	0	0	0
118	0	0	1	0	0	0	0
119	0	0	0	0	1	0	0
120	0	0	0	0	0	0	0
121	0	0	1	0	0	0	0
122	0	0	0	0	0	0	0
123	0	0	0	1	0	0	0
124	0	0	0	0	1	0	0
125	0	0	0	0	0	0	0
126	0	0	0	0	0	0	0
127	0	0	0	0	1	0	0
128	0	0	0	0	0	0	0
129	0	0	0	0	1	0	0
130	0	0	0	0	1	0	0
131	0	0	0	1	0	0	0

TABLE 20 (Continued)

		DoD	Other Criteria				
Project	IP	(as if)	IRR	ROI	CPM	NPV	EPI
132	0	0	0	0	1	0	0
133	0	0	0	1	0	0	0
134	0	0	0	0	0	0	0
135	0	0	0	0	0	0	0
136	0	0	0	0	0	0	0
137	0	0	0	1	0	0	0
138	0	0	0	0	1	0	0
139	0	0	0	0	0	0	0
140	0	0	0	0	0	0	0
141	0	0	0	0	0	0	0
142	0	0	0	1	0	0	0
143	0	0	0	0	1	0	0
144	0	0	0	0	0	0	0
145	0	0	0	0	0	0	0
146	0	0	0	0	0	0	0
147	1	0	0	0	0	0	0
148	0	0	0	0	0	1	0
149	1	0	0	0	0	0	0
150	0	0	0	0	1	0	0
151	0	0	0	0	0	0	0
152	0	0	0	0	0	0	0
153	0	0	0	0	0	0	0
155	0	0	0	0	1	0	0
156	0	0	0	0	0	0	0
157	0	0	0	0	0	0	0
158	0	0	0	0	1	0	0
159	0	0	0	0	0	0	0
160	0	0	0	0	1	0	0
161	0	0	0	0	0	0	0
162	0	0	0	0	1	0	0
163	0	0	0	0	0	0	0
164	0	0	0	0	0	0	0
165	0	0	0	0	0	0	0
166	0	0	0	0	0	0	0
167	0	0	0	0	0	0	0
168	0	0	0	0	0	0	0
169	0	0	0	0	0	0	0
170	0	0	0	0	0	0	0
171	0	0	0	0	0	0	0
172	0	0	0	0	0	0	0
173	0	0	0	0	0	0	0
174	0	0	0	0	0	0	0
175	0	0	0	0	0	0	0
176	0	0	0	0	0	0	0
177	0	0	0	0	0	0	0
178	0	0	0	0	0	0	0

TABLE 20 (Continued)

Project	IP	DoD (as if)	Other Criteria IRR	ROI	CPM	NPV	EPI
179	0	0	0	0	0	0	0
180	0	0	0	0	0	0	0
181	0	0	0	0	0	0	0
182	0	0	0	0	0	0	0
183	0	0	0	0	0	0	0
184	0	0	0	0	0	0	0
185	0	0	0	0	0	0	0
186	0	0	0	0	0	0	0
Total in mix	74	85	76	70	93	24	76

TABLE 21

CASH FLOW DATA ON MIXES SELECTED BY IP AND RANKING

(BUDGET CEILING = $73.1 MILLION)

		DoD Criteria		Other Criteria				
Year	IP	(as if)	(actual)	IRR	ROI	CPM	NPV	EPI
Savings (millions of dollars)								
0	0.0	0.1	0	0.1	0.0	0.2	0.0	0.0
1	77.7	87.7	90.4	108.3	71.4	91.9	53.6	78.8
2	189.5	134.5	114.6	169.0	176.1	95.2	164.7	182.0
3	156.0	138.4	129.8	132.6	137.6	100.3	134.5	143.6
4	174.4	146.4	137.9	150.9	155.9	116.7	158.8	161.9
5	173.0	154.5	146.2	149.3	154.3	59.5	156.8	160.3
6	119.7	106.9	105.6	89.4	104.0	59.6	104.9	104.4
7	120.0	107.0	105.9	88.6	104.1	59.8	105.1	104.6
8	120.4	107.1	106.3	88.6	104.2	44.9	105.4	104.7
9	113.3	90.2	89.6	66.6	96.9	45.4	80.4	96.1
10	109.2	90.2	89.9	66.6	96.9	39.4	80.7	96.1
11	95.0	80.6	74.6	48.6	89.6	37.6	73.7	86.3
12	83.5	78.0	62.3	46.0	87.7	37.1	64.0	83.7
13	83.5	77.5	61.5	45.2	87.7	37.1	64.0	83.7
14	83.5	77.5	61.5	45.2	87.7	35.8	64.0	83.7
15	82.2	76.2	61.2	43.9	86.4	27.0	64.0	82.4
16	69.1	66.9	49.0	30.8	73.4	27.0	58.6	69.4
17	69.1	66.9	49.0	30.8	73.4	27.0	58.6	69.4
18	69.1	66.9	49.0	30.8	73.4	27.0	58.6	69.4
19	69.1	66.9	49.0	30.8	73.4	26.8	58.6	69.4
20	67.7	65.4	49.0	29.6	71.9	26.3	58.6	67.9
21	67.2	64.7	49.0	29.2	70.7	26.3	58.6	67.4
22	67.2	64.7	49.0	29.2	70.7	26.3	58.6	67.4
23	67.2	64.7	49.0	29.2	70.7	26.3	58.6	67.4
24	67.2	64.7	49.0	29.2	70.7	26.3	58.6	67.4
25	67.2	64.7	49.0	29.2	70.7	26.3	58.6	67.4
26	40.5	38.0	21.7	2.5	43.7	0.0	40.5	40.5
Costs (millions of dollars)								
0	73.1	73.1	73.1	73.1	73.1	73.1	73.1	73.0
1	10.5	0.9	7.2	3.7	0.6	0.4	3.5	0.7
2	11.6	0.0	7.0	1.9	0.0	0.0	5.1	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 22

CASH FLOW DATA ON MIXES SELECTED BY IP AND RANKING

(BUDGET CEILING = $136.4 MILLION)

			Other Criteria				
YR	IP	DoD (as if)	IRR	ROI	CPM	NPV	EPI
Savings (millions of dollars)							
0	0.1	0.3	0.4	0.1	0.3	0.0	0.0
1	129.1	136.8	140.4	120.3	123.9	119.7	130.0
2	258.3	247.1	256.0	242.1	169.6	228.7	253.3
3	229.9	217.1	227.2	206.9	174.6	199.4	224.8
4	254.6	241.8	251.6	236.6	182.5	223.7	249.5
5	253.0	240.8	249.5	229.3	190.8	221.7	248.0
6	192.2	172.7	179.7	177.5	120.9	148.0	187.1
7	192.0	172.5	179.3	172.4	121.2	148.3	186.9
8	192.9	173.3	179.6	178.3	121.7	148.6	187.7
9	142.2	118.8	128.3	132.5	91.1	117.3	136.9
10	136.8	119.6	128.6	138.3	91.4	99.3	137.7
11	103.3	101.8	97.8	109.0	80.3	87.7	103.3
12	89.3	87.7	85.5	100.4	77.8	87.7	89.3
13	88.8	86.8	84.7	94.5	77.3	87.7	88.8
14	88.8	86.8	84.7	99.9	77.3	87.7	88.8
15	87.5	85.5	83.4	93.1	76.0	75.7	87.5
16	73.7	71.7	70.3	84.8	67.0	75.7	73.7
17	73.7	71.7	70.3	79.3	67.0	75.7	73.7
18	73.7	71.7	70.3	79.3	67.0	75.7	73.7
19	73.7	71.7	70.3	79.3	67.0	75.7	73.7
20	72.1	70.2	68.8	77.8	66.6	75.7	72.1
21	70.7	68.7	67.3	76.2	65.2	75.7	70.7
22	70.7	68.7	67.3	76.2	65.2	75.7	70.7
23	70.7	68.7	67.3	76.2	65.2	75.7	70.7
24	70.7	68.7	67.3	75.5	65.2	75.7	70.7
25	70.7	68.7	67.3	75.5	65.2	75.7	70.7
26	43.7	40.5	40.5	43.7	38.0	43.7	43.7
Costs (millions of dollars)							
0	136.4	136.3	136.4	136.3	136.3	136.4	136.3
1	15.3	6.0	8.6	4.2	2.3	6.2	8.2
2	11.6	5.1	7.0	5.1	0.0	7.0	7.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 23

MULTIPLE-CRITERIA SOLUTION MIXES

	ROI Model		Sequential GP Model	
Project	$ 73.1M Ceiling	$ 136.4M Ceiling	$ 73.1M Ceiling	$ 136.4M Ceiling
1	1	1	1	1
2	1	1	1	1
3	1	1	1	1
4	1	1	1	1
5	1	1	1	1
6	1	1	1	1
7	1	1	1	1
8	1	1	1	1
9	1	1	1	1
10	1	1	1	1
11	1	1	1	1
12	1	1	1	1
13	1	1	1	1
14	1	1	1	1
15	1	1	1	1
16	1	1	1	1
17	0	1	1	1
18	0	1	1	1
19	1	1	1	1
20	0	1	1	1
21	1	1	1	1
22	1	1	0	1
23	1	1	1	1
24	0	0	1	1
25	0	1	1	1
26	0	0	1	1
27	1	1	1	1
28	0	1	1	1
29	1	1	0	1
30	1	1	0	1
31	1	1	0	1
32	0	1	0	1
33	1	1	1	1
34	1	1	1	1
35	1	1	0	1
36	1	1	0	1
37	1	1	0	1
38	0	1	1	1
39	1	1	1	1
40	1	1	0	1

TABLE 23 (Continued)

Project	ROI Model $ 73.1M Ceiling	ROI Model $ 136.4M Ceiling	Sequential GP Model $ 73.1M Ceiling	Sequential GP Model $ 136.4M Ceiling
41	0	1	0	1
42	1	1	0	1
43	1	1	0	0
44	0	1	1	1
45	1	1	0	1
46	0	1	1	1
47	1	1	0	0
48	0	1	1	1
49	0	1	0	1
50	1	1	0	1
51	0	0	1	1
52	0	0	1	1
53	0	0	1	1
54	0	0	1	1
55	1	1	0	0
56	0	1	0	0
57	0	0	0	1
58	0	0	1	1
59	0	0	1	1
60	0	1	0	0
61	1	1	0	0
62	0	1	0	0
63	0	1	0	1
64	0	1	0	0
65	0	0	1	1
66	0	0	0	0
67	0	1	0	1
68	0	0	0	1
69	0	1	1	1
70	0	0	0	1
71	0	0	0	1
72	0	1	0	0
73	0	0	0	1
74	0	0	0	1
75	0	1	0	0
76	0	0	0	0
77	0	0	0	1
78	0	0	0	1
79	1	1	0	0
80	0	0	0	1
81	0	0	0	0
82	0	0	1	1
83	0	1	0	0
84	0	1	0	0
85	0	0	0	1

TABLE 23 (Continued)

Project	ROI Model $ 73.1M Ceiling	ROI Model $ 136.4M Ceiling	Sequential GP Model $ 73.1M Ceiling	Sequential GP Model $ 136.4M Ceiling
86	0	0	0	0
87	0	1	0	0
88	0	0	0	1
89	0	0	0	1
90	0	0	0	1
91	0	1	0	0
92	0	0	0	1
93	0	1	0	0
94	0	0	0	0
95	0	0	1	1
96	0	0	1	1
97	0	0	0	1
98	0	0	0	0
99	0	0	1	1
100	0	0	0	1
101	0	0	0	0
102	0	0	0	1
103	0	0	0	0
104	0	0	0	0
105	0	0	0	1
106	0	0	0	1
107	0	0	0	1
108	0	0	1	1
109	0	0	1	1
110	0	0	0	0
111	0	0	0	0
112	0	0	0	0
113	0	0	0	1
114	0	1	0	0
115	0	0	0	0
116	0	0	0	0
117	0	0	0	0
118	0	0	0	0
119	0	0	1	1
120	0	0	0	0
121	0	0	0	0
122	0	0	0	0
123	0	0	0	0
124	0	0	0	0
125	0	0	0	0
126	0	0	0	0
127	0	0	0	1
128	0	0	0	0
129	0	0	0	0
130	0	0	1	1

TABLE 23 (Continued)

Project	ROI Model $ 73.1M Ceiling	ROI Model $ 136.4M Ceiling	Sequential GP Model $ 73.1M Ceiling	Sequential GP Model $ 136.4M Ceiling
131	0	0	0	0
132	0	0	0	1
133	0	0	0	0
134	0	0	0	0
135	0	0	0	0
136	0	0	0	0
137	0	0	0	0
138	0	0	0	1
139	0	0	0	0
140	0	0	0	0
141	0	0	0	0
142	0	0	0	0
143	0	0	0	1
144	0	0	0	0
145	0	0	0	0
146	0	0	0	0
147	0	0	0	0
148	0	0	0	0
149	0	0	1	1
150	0	0	0	1
151	0	0	0	0
152	0	0	0	0
153	0	0	0	0
154	0	0	0	0
155	0	0	0	1
156	0	0	0	0
157	0	0	0	0
158	0	0	0	0
159	0	0	0	0
160	0	0	0	1
161	0	0	0	0
162	0	0	0	1
163	0	0	0	0
164	0	0	0	0
165	0	0	0	0
166	0	0	0	0
167	0	0	0	0
168	0	0	0	0
169	0	0	0	0
170	0	0	0	0
171	0	0	0	0
172	0	0	0	0
173	0	0	0	0
174	0	0	0	0
175	0	0	0	0

TABLE 23 (Continued)

Project	ROI Model $ 73.1M Ceiling	ROI Model $ 136.4M Ceiling	Sequential GP Model $ 73.1M Ceiling	Sequential GP Model $ 136.4M Ceiling
176	0	0	0	0
177	0	0	0	0
178	0	0	0	0
179	0	0	0	0
180	0	0	0	0
181	0	0	0	0
182	0	0	0	0
183	0	0	0	0
184	0	0	0	0
185	0	0	0	0
186	0	0	0	0
Total in Mix	39	66	51	96

TABLE 24

CASH FLOW DATA ON MULTIPLE-CRITERIA MODELS

(DOLLARS IN MILLIONS)

Year	ROI Model $ 73.1 Ceiling	ROI Model $ 136.4 Ceiling	Sequential GP Model $ 73.1 Ceiling	Sequential GP Model $ 136.4 Ceiling
Savings				
0	0.0	0.1	0.3	0.3
1	76.2	123.0	96.2	132.8
2	179.3	244.7	108.9	187.0
3	141.0	216.0	118.1	195.4
4	159.2	240.3	126.6	204.0
5	157.7	238.4	135.1	212.6
6	104.0	181.1	78.3	143.0
7	104.1	181.5	78.9	143.6
8	104.2	181.9	79.6	144.3
9	96.9	135.3	61.3	116.6
10	96.9	135.6	60.4	115.5
11	87.1	105.1	50.0	101.3
12	84.5	91.1	38.5	87.2
13	84.5	90.6	38.0	86.7
14	84.5	90.6	38.0	86.7
15	83.2	89.3	36.7	85.3
16	70.1	75.5	28.4	70.8
17	70.1	75.5	28.4	70.8
18	70.1	75.5	28.4	70.8
19	70.1	75.5	28.4	70.8
20	68.7	74.0	26.9	69.3
21	67.4	72.5	26.2	67.8
22	67.4	72.5	26.2	67.8
23	67.4	72.5	26.2	67.8
24	67.4	71.8	26.2	67.8
25	67.4	71.8	26.2	67.8
26	40.5	43.7	0.0	38.0
Costs				
0	73.1	72.0	73.1	136.3
1	7.8	0.7	7.6	9.0
2	9.7	0.0	5.1	5.1
3	0.0	0.0	0.0	0.0

SELECTED BIBLIOGRAPHY

Ackoff, R. and M. Sasieni. Fundamentals of Operations Research. New York: Wiley, 1968.

Arrow, K. and R. Lind. "Uncertainty and the Evaluation of Public Investment Decisions." American Economic Review 60 (June 1970), pp. 364-378.

Atkins, D. and D. Ashton. "Discount Rates in Capital Budgeting: A Re-examination of the Baumol and Quandt Paradox." The Engineering Economist 21 (Spring 1976), pp. 159-171.

Awerbuch, S., G. Ecker and W. Wallace. "A Note: Hidden Nonlinearities in the Application of Goal Programming." Management Science 22 (April 1976), pp. 918-920.

Balas, E. "An Additive Algorithm for Solving Linear Programs with Zero-One Varibles." Operations Research 13 (1965), pp. 517-546.

Banda, A. and T. Nolan. "An Empirical Study of the Capital Investment Decision Making Process in Selected Companies in 1971." Akron Business and Economic Review (1972).

Baum, S. "Observations on 'Discount Rates in Linear Programming Formulations of the Capital Budgeting Problem'." The Engineering Economist 30 (Spring 1985), pp. 292-293.

Baumol, W. Testimony before the Subcommittee on Economy in Government. Joint Economic Committee. The Planning, Programming, Budgeting System: Progress and Potentials. 90th Congress, 1st sess. (20 September 1967), pp. 129-179.

________. "On the Social Rate of Discount." American Economic Reivew 58 (September 1968), pp. 788-802.

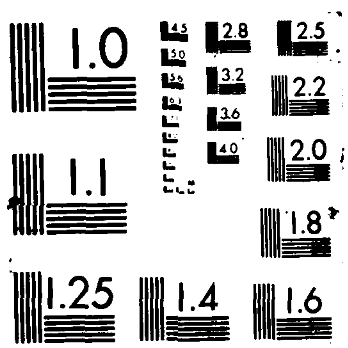
________ and R. Quandt. "Investment and Discount Rates under Capital Rationing--A Programming Approach." Economic Journal 75 (June 1965), pp. 317-329.

Beildleman, C. "Discounted Cash Flow Reinvestment [illegible] Assumptions." The Engineering Economist 29 [illegible] 1984), pp. 127-139.

AD-A186 153 THE APPLICATION OF MATHEMATICAL PROGRAMMING TO THE PRODUCTIVITY INVESTMEN..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH D S CHRISTENSEN 1987

3/3

UNCLASSIFIED AFIT/CI/NR-87-133D F/G 12/4 NL


1.0
4.5
2.8
2.5
5.0
3.2
5.6
2.2
6.3
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

Bernhard, R. "Discount Methods for Expenditure Evaluation: A Clarification of Their Assumptions." _Journal of Industrial Engineering_ 13 (January-February 1962), pp. 19-27.

________. "Mathematical Programming Models for Capital Budgeting--A Survey, Generalization, and Critique." _Journal of Financial and Quantitative Analysis_ 4 (June 1969), pp. 111-158.

________. "A Comprehensive Comparison and Critique of Discounting Indices Proposed for Capital Investment Evaluation." _The Engineering Economist_ 16 (Spring 1971), pp. 157-86.

Bhaskar, K. "Linear Programming and Capital Budgeting: A Reappraisal." _Journal of Business Finance and Accounting_ 3 (1976), pp. 29-37.

Bitran, G. and A. Novaes. "Linear Programming with a Fractional Objective Function." _Operations Research_ 21 (1973), pp. 22-29.

Blatt, J. "Investment Evaluation under Uncertainty." _Financial Management_ 8 (Summer 1979), pp. 66-81.

Bradley, S. and S. Frey. "Equivalent Mathematical Programming Models of Pure Capital Rationing." _Journal of Financial and Quantitative Analysis_ 13 (June 1978), pp. 345-361.

________, R. Frank and S. Frey. "Determining the Appropriate Discount Rates in Pure Capital Rationing." _Decision Sciences_ 9 (July 1978), pp. 391-401.

________ and S. Frey. "Capital Rationing and Discounting in Public Sector Investment Decisions." _OMEGA_ 7 (1979), pp. 77-79.

Brigham, E. _Financial Management, Theory and Practice_. Hirsdale, Illinois: The Dryden Press, 1977.

Bryne, R., A. Charnes, W. Cooper and K. Kortanek. "A Chance-Constrained Approach to Capital Budgeting with Portfolio Type Payback and Liquidity Constraints and Horizon Posture Controls." _Journal of Financial and Quantitative Analysis_ 2 (December 1967), pp. 339-364.

Burton, R. and W. Damon. "On the Existence of a Cost of Capital under Pure Capital Rationing." _Journal of Finance_ 29 (September 1974), pp. 1165-1174.

Bussey, Lynn E. The Economic Analysis of Industrial Projects. Englewood Cliffs: Prentice-Hall, 1978.

Carleton, W. "Linear Programming and Capital Budgeting Models: A New Interpretation." Journal of Finance 24 (December 1969), pp. 825-833.

Charnes, A. and W. Cooper. Management Models and Industrial Applications of Linear Programming, Volumes I and II. New York: Wiley and Sons, Inc., 1961.

________. "Programming with Linear Fractional Functionals." Naval Research Logistics Quarterly 9 (1962), pp. 181-186.

________. "Deterministic Equivalents for Optimizing and Satisficing under Chance Constraints." Operations Research 11 (January 1963), pp. 18-39.

________ and M. Miller. "Application of Linear Programming to Financial Budgeting and the Costing of Funds." Journal of Business 32 (January 1959), pp. 20-46.

Clark, J., Hindelang, T. and R. Pritchard. Capital Budgeting. Englewood Cliffs: Prentice-Hall, 1979.

Coats, D. "An Assets Approach to Estimating the Public Discount Rate for Public Investments." Masters Thesis, Air Force Institute of Technology GOR/OS/84D-2, December 1984.

Crowder, H., E. Johnson and M. Padberg. "Solving Large Scale Zero-One Linear Programming Problems." Operations Research 31 (Sept-Oct 1983), pp. 803-829.

Danzig, G. Linear Programming and Extensions. New Jersey: Princeton University Press, 1963.

Dean, J. Capital Budgeting. New York: Columbia University Press, 1951.

Demski, J. and D. Kreps. "Models in Managerial Accounting." Journal of Accounting Research 20, Supplement (1982), pp. 117-148.

Department of Defense Instruction 5010.31. "DoD Productivity Program," 1975. Reissued 27 April 1979.

Department of Defense Instruction 5010.34. "Productivity Enhancement, Measurement, and Evaluation--Operating Guidelines and Reporting Instructions," 4 August 1975.

Department of Defense Instruction 5010.36. "Productivity Enhancing Capital Investments," December 1980.

Department of Defense Instruction 7041.3. "Economic Analysis and Program Evaluation for Resource Management," October 1972.

Ederington, L. and W. Henry. "On Costs of Capital In Programming Approaches to Capital Budgeting." Journal of Financial and Quantitative Analysis 14 (December 1979), pp. 1049-1057.

Elton, E. "Capital Rationing and External Discount Rates." Journal of Finance 25 (June 1970), pp. 573-584.

Farragher, E. "Capital Budgeting Practices of Non-Industrial Firms." The Engineering Economist 31 (Summer 1986), pp. 293-302.

Feldstein, M. "The Social Time Preference Discount Rate in Cost-Benefit Analysis."Economic Journal 74 (June 1974), pp. 360-379.

Finn, F. "Integer Programming, Linear Programming and Capital Budgeting." ABACUS (December 1973), pp. 180-192.

Fisher, G. Cost Considerations in Systems Analysis. New York: American Elseview Co., 1971.

Fisher, I. The Theory of Interest. New York: Macmillan Publishing Co., 1930.

Folger, H. "Ranking Techniques and Capital Budgeting" The Accounting Review 47 (1972), pp. 134-143.

Forsyth, J. and D. Owen. "Capital Rationing Methods." In Capital Budgeting under Conditions of Uncertainty, pp. 213-235. Edited by R. L. Crum and F. G. Derkinderen. Boston: Martinus Nijhoff Publishing Co., 1981.

Freeland, J. and M. Rosenblatt. "An Analysis of Linear Programming Formulations for the Capital Rationing Problem." The Engineering Economist 24 (Fall 1978), pp. 49-61.

General Management Systems. Qualification of Productivity Enhancing Investment Potential. Falls Church, Virginia: Defense Productivity Office, 1986.

Geoffrion, A. "Integer Programming by Implicit Enumeration and Balas' Method." SIAM Review 9 (1967), pp. 178-190.

________. "An Improved Implicit Enumeration Approach for Integer Programming."Operations Research 17 (May-June 1969), pp. 437-454.

________ and R. Nauss. "Parametric and Postoptimality Analysis in Integer Programming."Management Science 23 (January 1977), pp. 453-466.

Gitman, L. and J. Forrester. "A Survey of Capital Budgeting Techniques by Major U.S. Firms." Financial Management 6 (Fall 1977), pp. 66-71.

Glover, F. "A Multiphase Dual Algorithm for the Zero-One Integer Programming Problem. Operations Research 13 (1965), pp. 879-919.

________. "Management Decision and Integer Programming." The Accounting Review 44 (April 1969), pp 300-303.

________ and C. McMillan. "The General Employee Scheduling Problem: An Integration of MS and AI." Computers and Operations Research 13 (1986), pp. 563-573.

Gomory, R. "Outline of an Algorithm for Integer Solutions to Linear Programs." Bulletin of the American Mathematical Society 64 (September 1958), pp. 275-278.

Gordon, L., D. Larcker and F. Tuggle. "Informational Impediments to the Use of Capital Budgeting Models." OMEGA 7 (1979), pp. 76-74.

Gue, R., J. Liggett and K. Cain. "Analysis of Algorithms for the Zero-One Programming Problem." Communications of the ACM 11 (December 1968), pp. 837-844.

Guranani, C. "Capital Budgeting: Theory and Practice." The Engineering Economist 30 (Fall 1984), pp. 19-46.

Hannan, E. "Linear Goal Programming with Multiple Fuzzy Goals." Fuzzy Sets and Systems 6 (1981a), pp. 235-248.

________. "On 'An Interpretation of Fractional Objectives in Goal Programming as Related to Papers by Awerbuch, et al., and Hannan.'" Management Science 27 (July 1981b), pp. 847-843.

________. "Goal Programming: Methodological Advances in 1973-1982 and Prospects for the Future." In MCDM: Past Decade and Future Trends, A Source Book of Multiple Criteria Decision Making, pp. 117-151. Edited by M. Zeleny. Greenwich, Connecticut: Jai Press, 1984.

Harberger, A. Testimony before the Subcommittee on Economy in Government, Joint Economic Committee. Economic Analysis of Public Investment Decisions: Interest Rate Policy and Discounting Analysis, 90th Congress, 2d sess. (31 July 1968), pp. 57-65.

________. "On Measuring the Social Opportunity Cost of Public Funds." The Discount Rate in Public Investment Evaluation, Report 17. Conference Proceedings from the Committee on the Economics of Water Resources Development of the Western Agrigcultural Economics Research Council, Denver, Colorado (17-18 December 1968).

Haveman, R. "The Opportunity Cost of Displaced Private Spending and the Social Discount Rate." Water Resources Research 5 (October 1969), pp. 947-957.

Hayes, J. "Discount Rates in Linear Programming Formulations of the Capital Budgeting Problem." The Engineering Economist 29 (Winter 1984), pp. 113-126.

________. "Reply to 'Observations on Discount Rates in Linear Programming Formulations of the Capital Budeting Problem." The Engineering Economist 30 (Summer 1985), pp. 397-398.

Headly, M. "An Analysis of the Multiple Objective Capital Budgeting Problem via Fuzzy Linear Integer (0-1) Programming." Masters Thesis, University Park, The Pennsylvania State University, 1980.

Hertz, D. "Risk Analysis in Capital Investment." Harvard Business Review 42 (January-February, 1964), pp. 95-106.

Hillier, F. "Chance-Constrained Programming with Zero-One or Bounded Continuous Decision Variables." Management Science 14 (September 1967), pp. 34-57.

________. The Evaluation of Risky Interrelated Investments. Amsterdam: North-Holland Publishing Company, 1969.

Hirshleifer, J. "On the Theory of Optimal Investment Decisions." Journal of Political Economy 66 (August 1958), pp. 329-352.

_______. Investment, Interest and Capital. Englewood Cliffs, New Jersey: Prentice-Hall, 1970.

Hodgman, D. "Credit Risk and Credit Rating." Quarterly Journal of Economics 74 (May 1960), pp. 258-278.

Horngren, C. and G. Foster. Cost Accounting, A Managerial Emphasis, 6th Edition. Englewood Cliffs: New Jersey, 1987.

Howe, K. "On DCF Reinvestment Rate Assumptions: A Clarification." The Engineering Economist 31 (Fall 1985), pp. 43-49.

Hughes, J. and W. Lewellen. "Programming Solutions to Capital Rationing Problems." Journal of Business Finance and Accounting 1 (Spring 1974), pp. 55-74.

IBM Mixed Integer Programming/370 Program Reference Manual, 2nd ed. IBM Corporation, 1975. Form number SH19-1099.

IBM Mathematical Programming System Extended/370 Program Reference Manual, 4th ed. IBM Corporation, 1979a. Form number SH19-1095.

IBM Mathematical Programming System Extended/370 Primer, 2d ed. IBM Corporation, 1979b. Form number GH-1091-1.

IBM Mathematical Programming System Extended/370 General Information Manual, 5th ed. IBM Corporation, 1979c. Form Number GH19-1090-4.

IBM Licensed Program Specifications for Mathematical Programming System Extended/370, Mixed Integer Programming /370. IBM Corporation, November 1986. Form Number GH19-1093-7.

Ignizio, J. Goal Programming and Extensions. Lexington, Mass.: Lexington Books, 1976a.

_______. "An Approach to the Capital Budgeting Problem with Multiple Objectives." The Engineering Economist 21 (Summer 1976b), pp. 259-272.

_______. "Solving Large-Scale Problems: A Venture into a New Dimension." Journal of Operations Research Society 31 (1980), pp. 217-225.

_______. "Capital Budgeting via Interactive Goal Programming." 1981 Fall Industrial Engineering Conference Proceedings, pp. 269-274.

________. Introduction to Linear Goal Programming. Sage University Paper Series on Quantitative Applications in the Social Sciences, series no. 07-056. Beverly Hills: Sage Publications, Inc., 1985a.

________. "Multiobjective Mathematical Programming via the MULTIPLEX Model and Algorithm." European Journal of Operational Research 22 (1985b), pp. 338-346.

________. "Integer Goal Programming via Goal Aggregation." Large Scale Systems 8 (1985c), pp. 81-86.

________ and J. Perlis. "Sequential Linear Goal Programming: Implementation via MPSX. Computers and Operations Research 5 (1980), pp. 406-410.

Ijiri, Y. Management Goals and Accounting for Control. Amsterdam: North Holland Publishing Co., 1965.

Jensen, R. "Sensitivity Analysis and Integer Programming." The Accounting Review 48 (July 1968), pp. 425-446.

Joksch, H. "Programming with Fractional Linear Objective Functions." Naval Research Quarterly 11 (1964), pp. 197-204.

Kaplan, R. "The Evolution of Management Accounting." The Accounting Review 59 (July 1984), pp. 390-418.

________. "The Role for Empirical Research in Management Accounting." Accounting, Organizations and Society 11 (1986), pp. 429-452.

Keane, S. "Let's Scrap IRR Once and for All!" Accountancy 85 (February 1974), pp. 78-82.

Keen, P. "The Evolving Concept of Optimality." In Multi-Criteria Decision Making, pp. 31-57. Edited by M. Starr and M. Zeleny. New York: North Holland Publishing Co., 1977.

Klammer, T. "Empirical Evidence of the Application of Sophisticated Capital Budgeting Techniques." Journal of Business 45 (July 1972), pp. 387-397.

Klemstine, C. and M. Maher. Management Accounting Research: 1926-1983. American Accounting Association, 1983.

Kornbluth. J. "A Survey of Goal Programming." Omega 1 (1973), pp. 193-205.

________. "Fractional Programming in MCDM." In MCDM: Past Decade and Future Trends, A Source Book of Multiple Criteria Decision Making, pp. 153-167. Edited by M. Zeleny. Greenwich, Connecticut: Jai Press, 1984.

________ and R. Steuer. "Goal Programming with Linear Fractional Criteria." European Journal of Operational Research 8 (1981), pp. 58-65.

Krutilla, J. and O. Eckstein. Multiple Purpose River Development: Studies in Applied Economic Analysis. Baltimore: Johns Hopkins University Press, 1958.

Kryzanowski, L., P. Lusztig and B. Schwab. "Monte Carlo Simulation and Capital Expenditure Decisions--A Case Study." The Engineering Economist 18 (Fall 1972), pp. 31-48.

Land, A. and A. Doig. "An Automatic Method for Solving Discrete Programming Problems." Econometrica 28 (1960), pp. 497-520.

Lee, S. Goal Programming for Decision Analysis. Philadelphia: Auerbach Publishing Co., 1972.

________ and A. Lerro. "Capital Budgeting for Multiple Objectives." Financial Management 3 (Spring 1974), pp. 58-66.

________ and R. Morris. "Integer Goal Programming Methods." In Multiple Criteria Decision Making, pp. 173-298. Edited by M. Starr and M. Zeleny. Amsterdam: North-Holland Publishing Company, 1977.

________, L. Moore and B. Taylor III. Management Science 2d. ed. Dubuque, Iowa: W. Brown Publishers, 1985.

Lenio, E. "The Introduction of Uncertainty Techniques to the Productivity Investment Fund." Thesis, Naval Post Graduate School, Monterey, California, 1984.

Lerner, E. and A. Rappaport. "Limit DCF in Capital Budgeting." Harvard Business Review 46 (September-October 1968), pp. 133-137.

Lin, W. "A Survey of Goal Programming Applications." Omega 8 (1980), pp. 115-117.

Lindsay, J. and A. Sametz. Financial Management: An Analytic Approach. Homewood, Illinois: Richard D. Irwin, Inc., 1967).

Lorie, J. and L. Savage. "Three Problems in Capital Rationing." The Journal of Business 28 (October 1955), pp. 229-239.

Lumpy, S. Investment Appraisal Wokingham, Berkshire, England: Van Nostrand Reinhold Co., 1984.

Lusztig, P. and B. Schwab. "A Note on the Application of Linear Programming to Capital Budgeting." Journal of Financial and Quantitative Analysis 3 (December 1968), pp. 427-431.

Mann, P. "Congress Scrutinizing Problems of Contract Overhead Charges." Aviation Week and Space Technology 122 (March 1985), pp. 293-4.

Mao, J. and B. Wallingford. "An Extension of Lawler and Bell's Method of Discrete Optimization." Management Science 15 (October 1968), pp. B51-61.

Marglin, S. "The Social Rate of Discount and the Optimal Rate of Investment." Quarterly Journal of Economics 77 (February 1963), pp. 95-112.

Masud, A. and C. Hwang. "Interactive Sequential GP." Journal of Operational Research Society 32 (1981), pp. 391-400.

Merville, L. and L. Travis. "A Generalized Model for Capital Investment." Journal of Finance 28 (March 1973), pp. 109-118.

Moore, C. and R. Jaekicke. Managerial Accounting. Toronto: Macmillan, 1963.

Myers, S. "A Note on Linear Programming and Capital Budgeting." Journal of Finance 27 (March 1972), pp. 93-96.

Naslund, B. "A Model of Capital Budgeting under Risk." Journal of Business 39 (April 1966), pp. 257-271.

Oakford, R., A. Salazar and S. Bhimjee. "Who Needs a Discount Rate." The Engineering Economist 24 (Summer 1979), pp. 259-265.

Office of Management and Budget Circular No. A-94. "Discount Rates to be used in Evaluating Time-distributed Costs and Benefits," March 1972.

Osteryoung, J. "Multiple Goals in the Capital Budgeting Decision," pp. 445-457. In Multiple Criteria Decision Making. Edited by J. Cochrane and M. Zeleny. Columbia, South Carolina: University of South Carolina Press, 1973.

________. Capital Budgeting: Long-term Asset Solution. Grid, Inc., 1974.

Payne, S., J. Tasini, D. Griffiths and E. Clark. "Forget the $400 Hammers: Here's Where the Big Money is Lost." Business Week (July 8 1985), pp. 48-50.

Para-Vasquez, A. and R. Oakford. "Simulation as a Technique for Comparing Decision Procedures." The Engineering Economist 21 (Summer 1976), pp. 221-236.

Petersen, C. "Solution of Capital Budgeting Problems having Chance Constraints; Heuristic and Exact Methods." AIIE Transactions 7 (June 1975), pp. 153-158.

Pettway, R. "Integer Programming in Capital Budgeting: A Note On Computational Experience." Journal of Financial and Quantitative Analysis 8 (September 1973), pp. 665-672.

Pigou, A. The Economics of Welfare. London: Macmillan Publishing Company, 1932.

Pinches, G. "Myopia, Capital Budgeting and Decision Making." Financial Management (Autumn 1982), pp. 6-19.

Prest, A. and R. Turvey. "Cost-Benefit Analysis: A Survey." Economic Journal 75 (December 1965), pp. 683-735.

Quirin, G. and J. Wiginton. Analyzing Capital Expenditures, Public and Private Perspectives. Homewood, Illinois: Richard Irwin, Inc., 1981.

Rappaport, A. "Integer Programming and Managerial Analysis." The Accounting Review 44 (April 1969), pp. 297-299.

Rasmussen, L. "Zero-one Programming with Multiple Criteria." European Journal of Operational Research 26 (1986), pp. 83-95.

Robichek, A., D. Ogilive and J. Roach. "Capital Budgeting: a Pragmatic Approach" Financial Executive 37 (April 1969), pp. 26-38.

Salazar, R. and S. Sen. "A Simulation Model of Capital Budgeting under Uncertainty." Management Science 15 (December 1968), pp. 161-179.

Schrage, L. Linear, Integer, and Quadratic Programming With LINDO. Palo Alto: The Scientific Press, 1984.

Schwab, B. and P. Lusztig. "A Comparative Analysis of the Net Present Value and the Benefit-Cost Ratio as Measures of Economic Desirability of Investments." Journal of Finance 24 (June 1969), pp. 507-516.

Shishko, R. Choosing the Discount Rate for Defense Decision Making R-1953-RC. Santa Monica, California: Rand Corporation, July 1976.

Simon, H. Models of Man. New York: Wiley, 1957.

_______. The Sciences of the Artificial. Cambridge, Mass.: M.I.T. Press, 1969.

Silhan, P. "Management Accounting is Research." Management Accounting (September 1982), pp. 38-42.

Solomon, E. "The Arithmetic of Capital Budgeting Decisions." Journal of Business 29 (April 1956), pp. 124-129.

Somers, H. "On the Demise of the Social Discount Rate." Journal of Finance 26 (May 1971), pp. 565-578.

Soyster, A. and B. Lev. "An Interpretation of Fractional Objectives in Goal Programming as Related to Papers by Awerbuch, et al., and Hannan." Management Science 24 (1978), pp. 1546-1549.

Spronk, J. Interactive Multiple Goal Programming, Applications to Financial Planning. Boston: Martinus Nijhoff Publishing Company, 1981.

Stockfisch, J. Testimony before the Subcommittee on Economy in Government, Joint Economic Committee. The Planning, Programming, Budgeting System: Progress and Potentials. 90th Congress, 1st sess. (20 September 1967), pp. 133-143.

Sundem, G. "Evaluating Simplified Capital Budgeting Models Using a Time-state Preference Metric." The Accounting Review 49 (April 1974), pp. 306-320.

Swanson, L. "Capital Rationing and Mathematical Programming: A Solution to the Elusive Discount Rate(s)." Journal of Financial and Quantitative Analysis 3 (December 1968), pp. 453-466.

Teichroew, D., A. Robichek and M. Montalbano. "Mathematical Analysis of Rates of Return Under Certainty." Management Science 11 (January 1965), pp. 395-403.

________. "An Analysis of Criteria for Investment and Financing Decisions Under Certainty." Management Science 12 (November 1965), pp. 151-179.

The Scientific Press. Advertisement brochure for LINDO. Palo Alto, California: The Scientific Press, Fall 1986.

Waters, L. "Research and Development Project Selection, Inter-dependence and Multi-period Probabilistic Budget Constraints." Doctoral Dissertation, Arizona State University, 1966.

Weingartner, H. "The Excess Present Value Index--A Theoretical Basis and Critique." Journal of Accounting Research 1 (Autumn 1963), pp. 213-224.

________. Mathematical Programming and the Analysis of Capital Budgeting Problems. Englewood Cliffs, New Jersey: Prentice Hall, 1963; reprint ed., Chicago: Markham Publishing Company, 1967.

________. "Some New Views on the Payback and Capital Budgeting Decision." Management Science 15, (August 1969), pp. B594-B607.

________. "Capital Rationing: n Authors in Search of a Plot." The Journal of Finance 32 (December 1977), pp. 1403-1431.

White, B. and G. Smith. "Comparing the Effectiveness of Ten Capital Investment Ranking Criteria." The Engineering Economist 31 (Winter 1986), pp. 151-163.

Whitmore, G. and L. Amey. "Capital Budgeting under Rationing: Comments on the Lustig and Schwab Procedure." Journal of Financial and Quantitative Analysis 8 (January 1973), pp. 127-135.

Woolsey, G. "Comment On Briskin's Note." Management Science 17 (March 1971), pp. 500-501.

Wysocki, R. "OR/MS Implementation Research: A Bibliography." Interfaces 9 (1979), pp. 37-41.

Zeleny, M. "On the Squandering of Resources and Profits via Linear Programming." Interfaces 11 (1981), pp. 101-107.

________, ed. MCDM: Past Decade and Future Trends. Greenwich, Connecticut: JAI Press, 1984.

Zimmerman, H. "Fuzzy Programming and Linear Programming with Several Objective Functions." International Journal of Fuzzy Sets and Systems 1 (1978), pp. 45-55.

Zimmerman, J. "Budget Uncertainty and the Allocation Decision in a Nonprofit Organization" Journal of Accounting Research 14 (Autumn 1976), pp. 301-319.

END

12-87

DTIC